

# Toxic Modeling in Baltimore Harbor

**Harry V. Wang**

**Jing Lin**

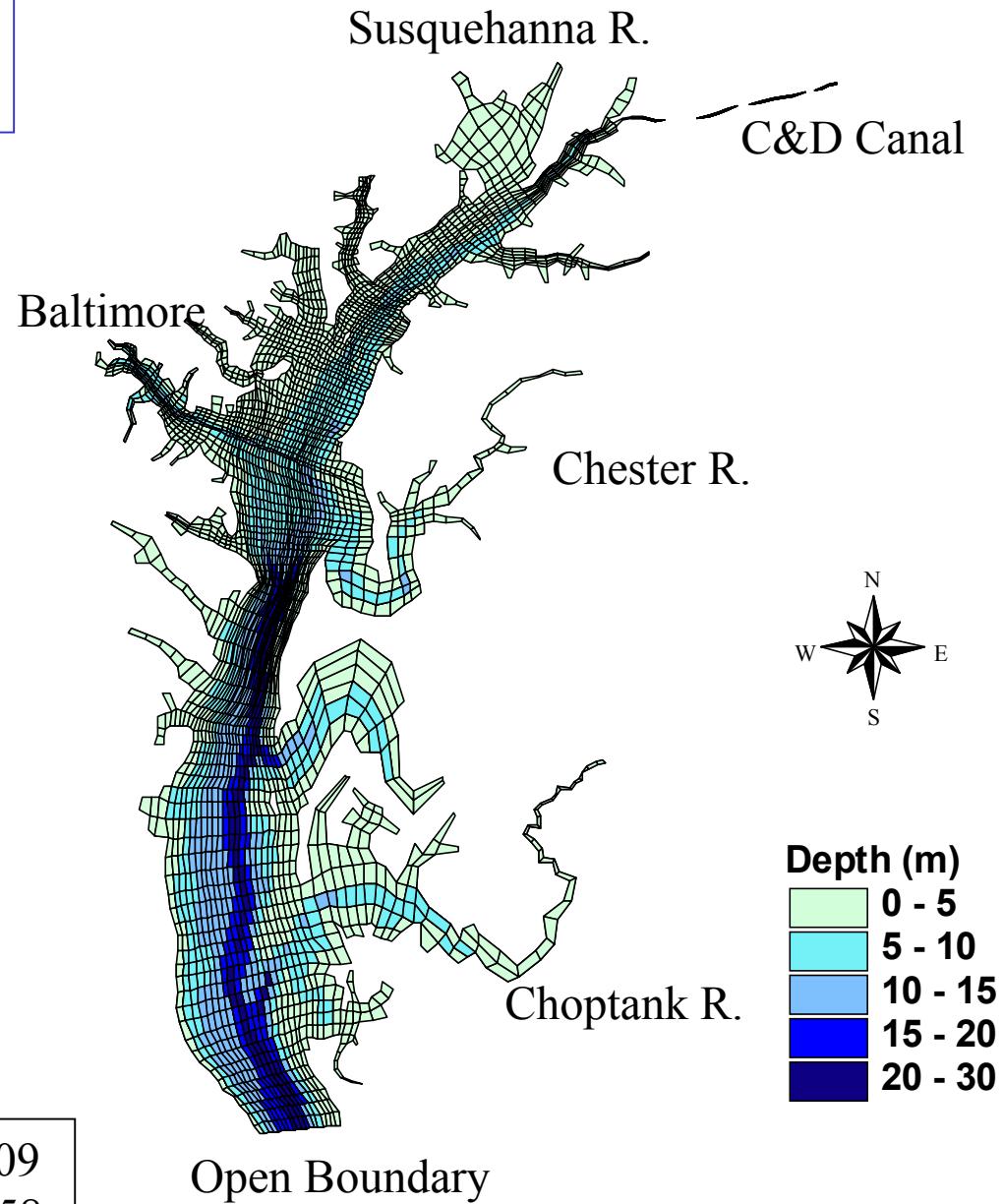
**Virginia Institute of Marine Science /  
School of Marine Science  
College of William and Mary**

# Contents

- **Introduction**
  - a. Hydrodynamic Model
  - b. Sediment Model
  - c. Toxic Model
- **Toxic Model Calibration**
- **Scenario Model Runs**
- **Sensitivity Test**

## Hydrodynamics and Sediment Transport Model Grid

Total Boxes: 16309  
Total Surface Boxes: 3758  
Vertical Layers: 19



# NUMERICAL HYDRODYNAMIC MODEL:CH3D-WES

- Three-dimensional free surface, hydrodynamic model (Johnson et al, 1990; Wang and Chapman, 1995)
- Non-orthogonal boundary fitted coordinates
- finite difference scheme
- Computing information
  - Total of 16309 active grid cells with 3758 being surface cells
  - Horizontal resolution: 0.2 km lateral and 0.4 km longitudinal
  - Time step 3 minutes: perform in Dec-alpha; 18 hour cpu for 365 days

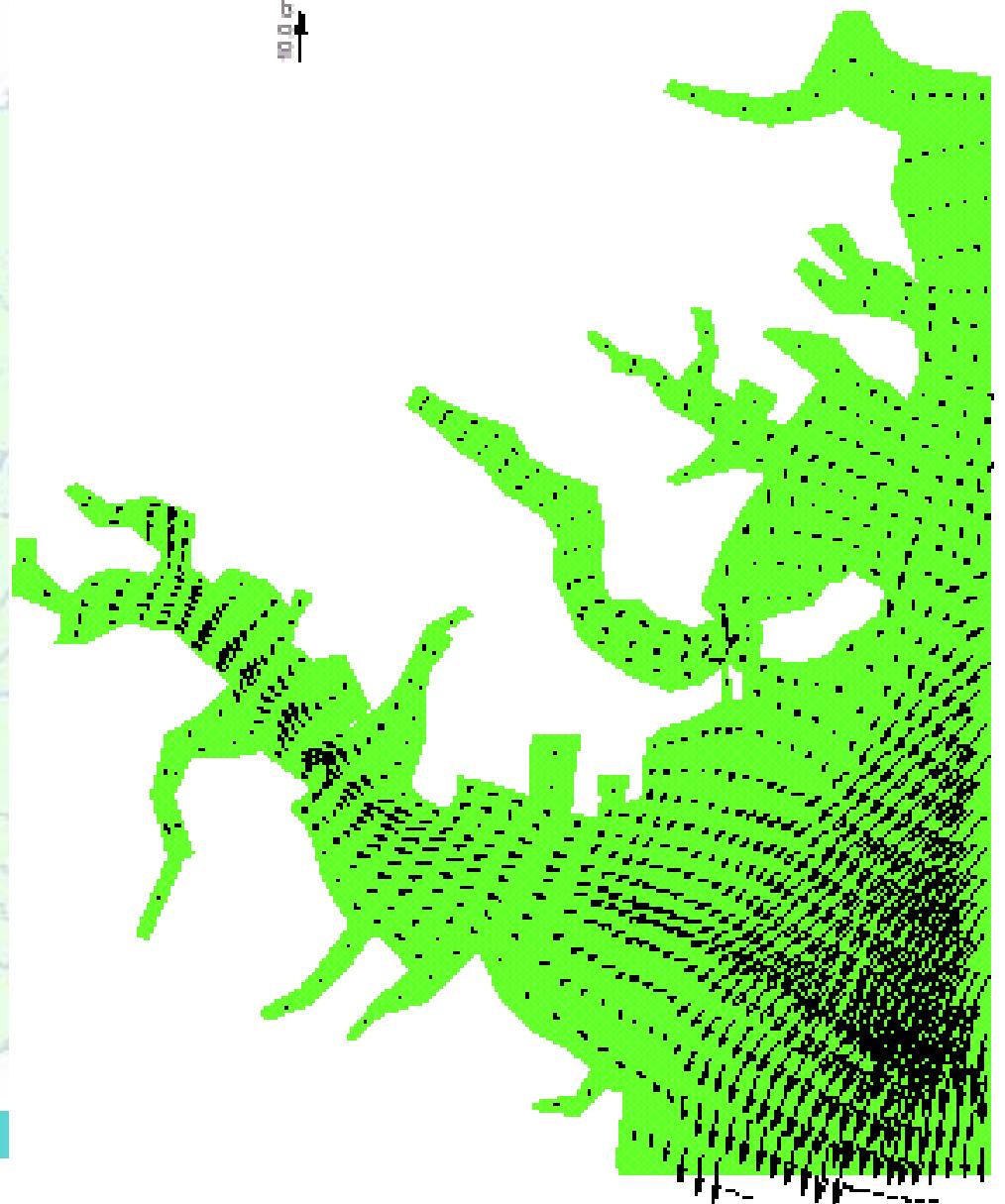
## Approach

- **Hydrodynamic input:**

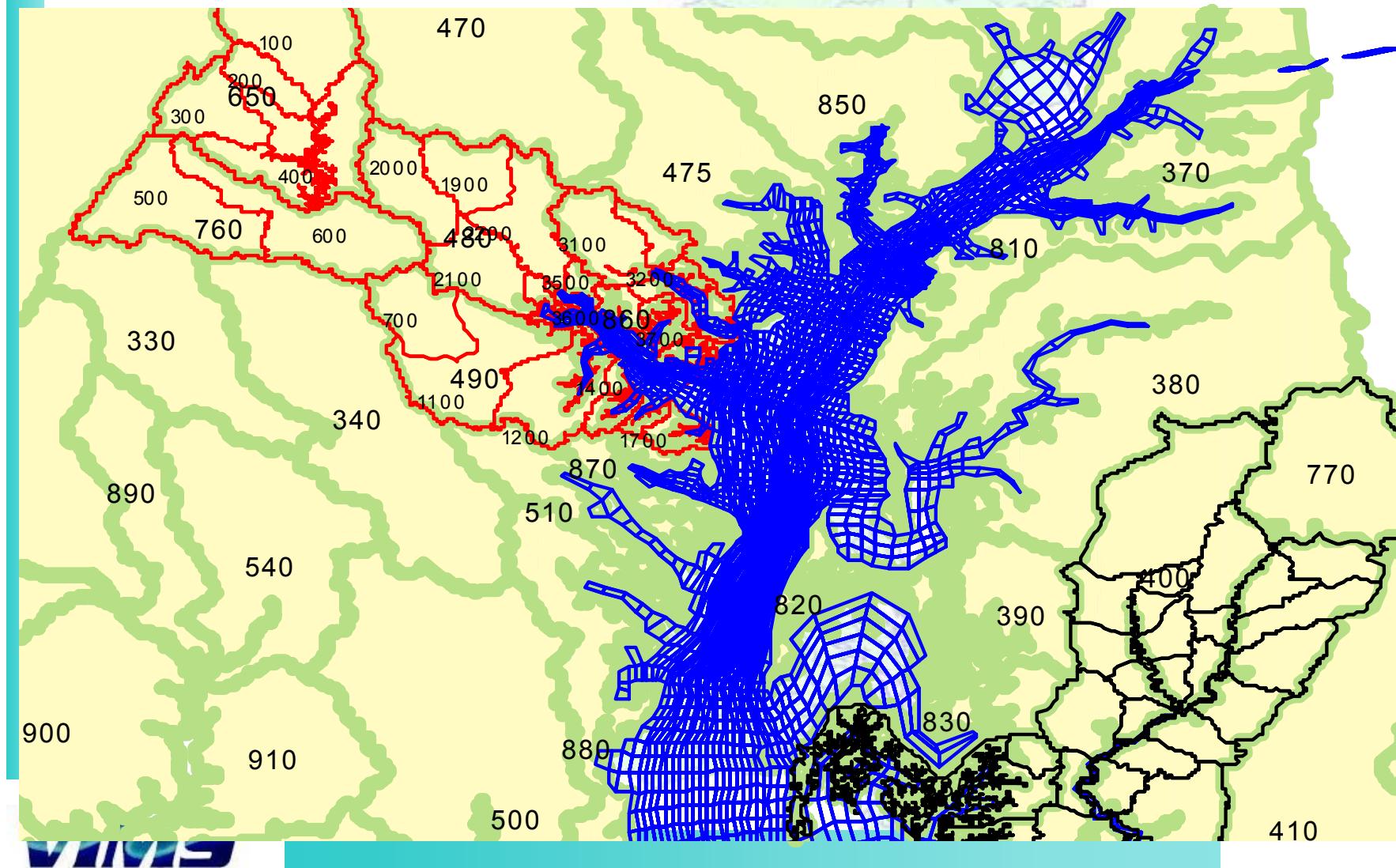
**Salinity, Temperature, Tidal elevation, Initial condition, Boundary condition**

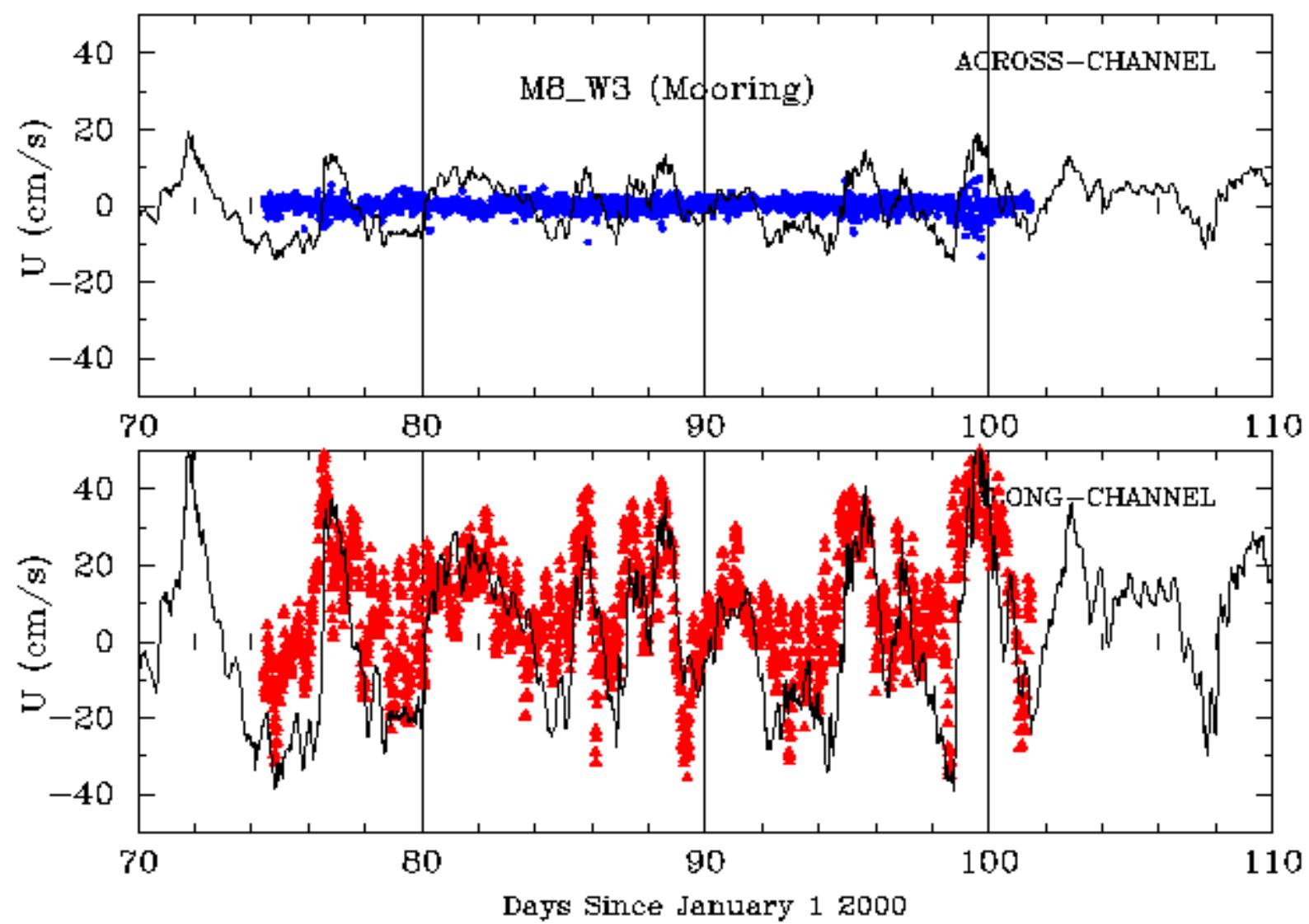
- **Outputs:**

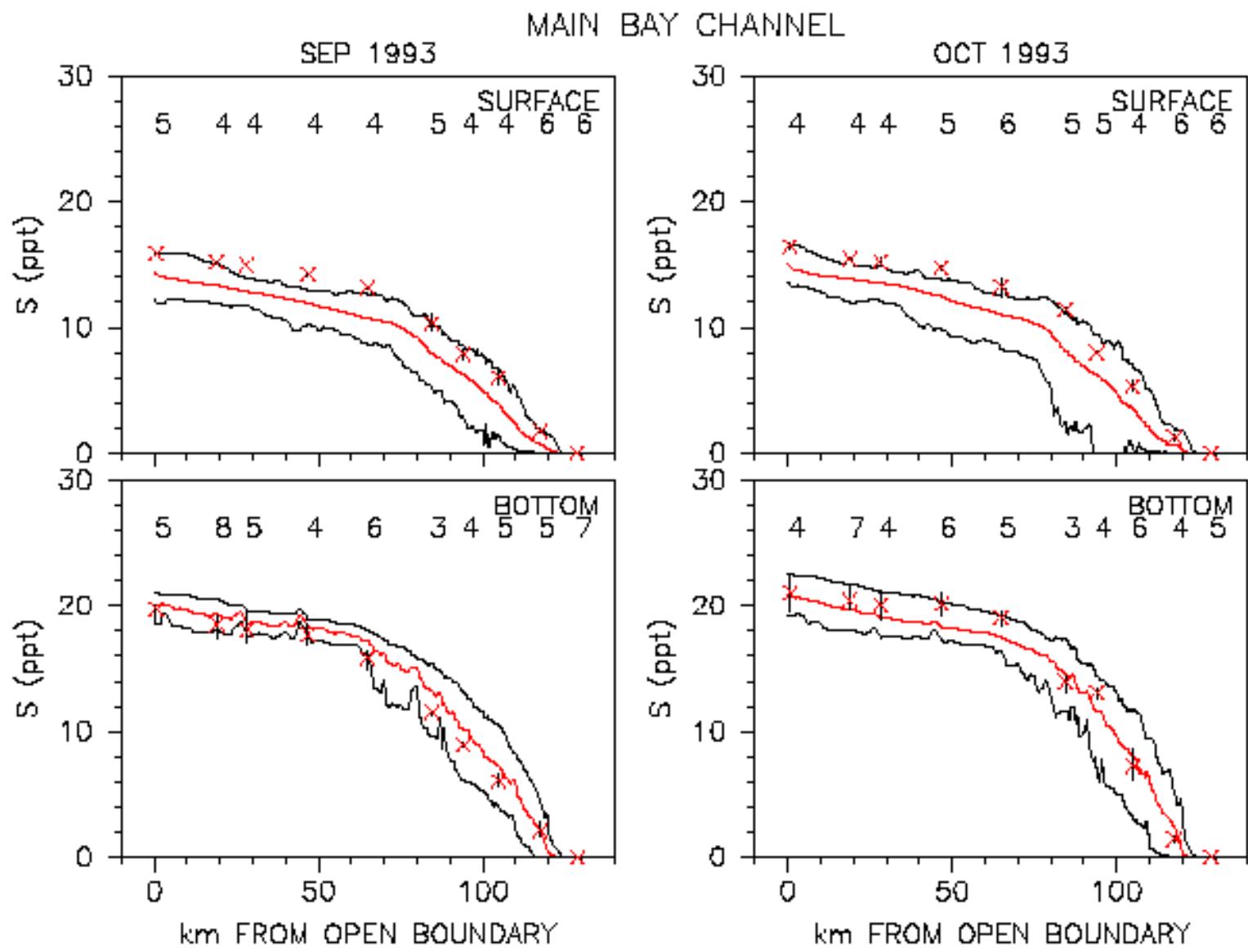
**3D-velocity, tidal elevation, salinity, temperature**

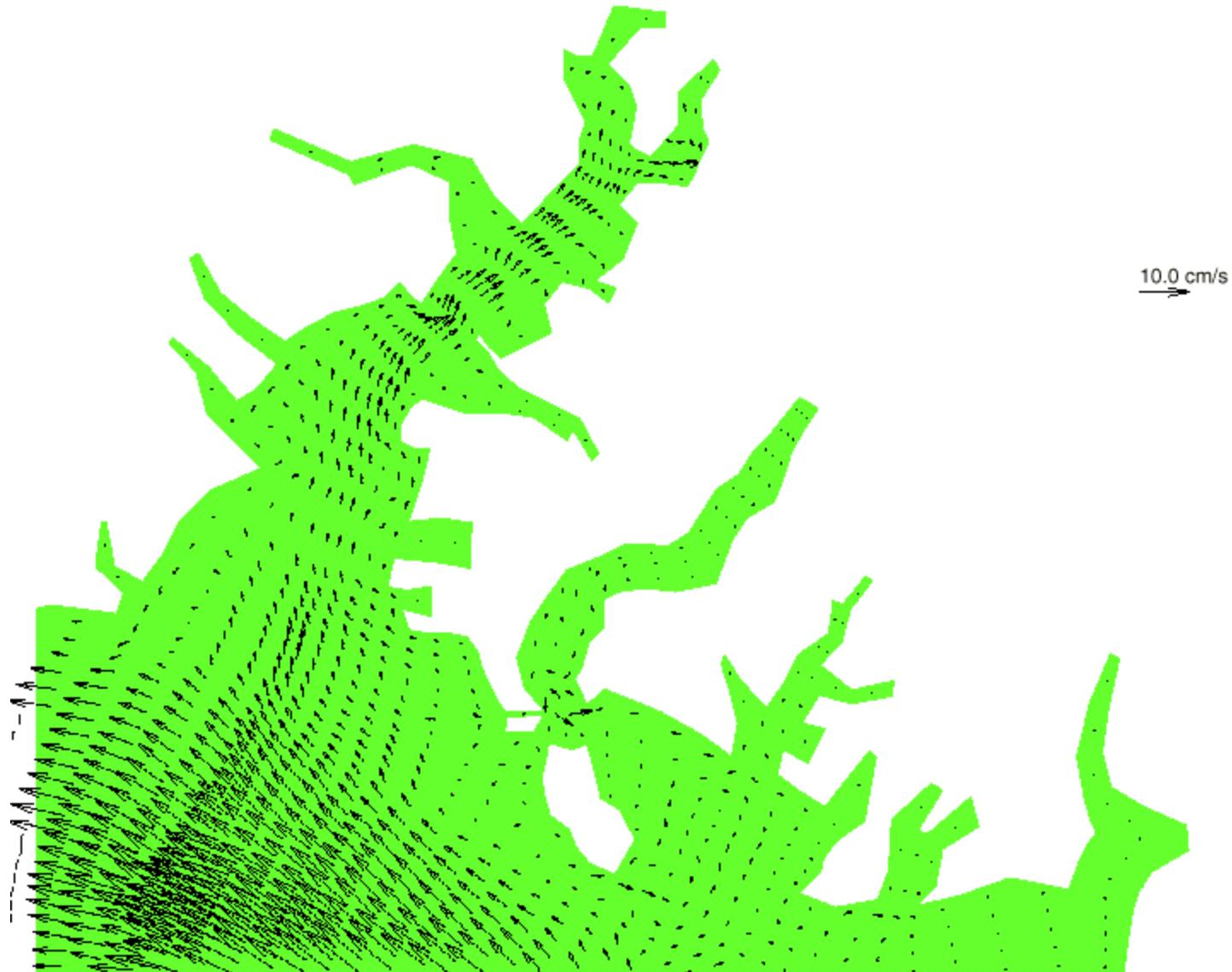


# Non-point sources

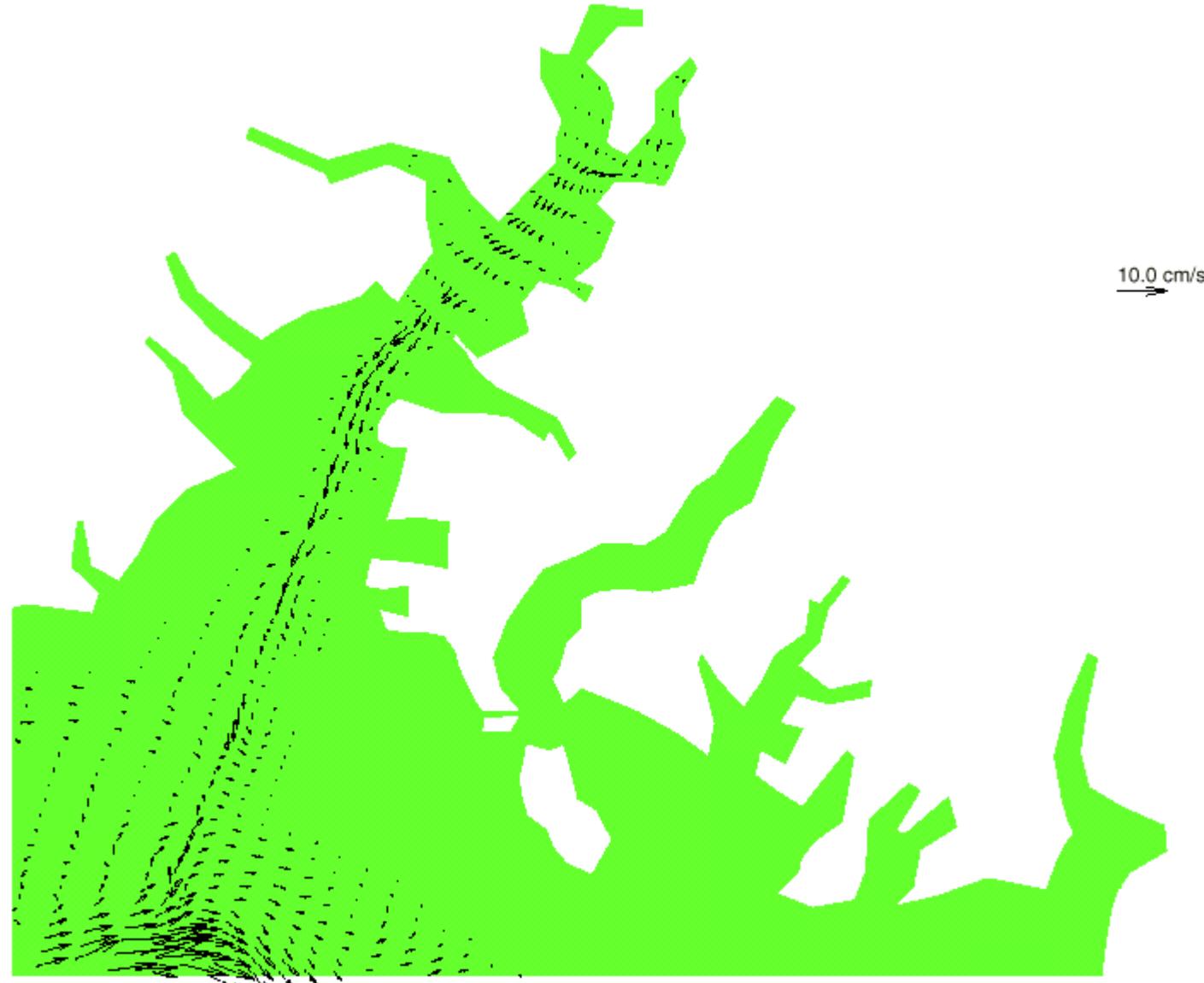








Surface layer circulation



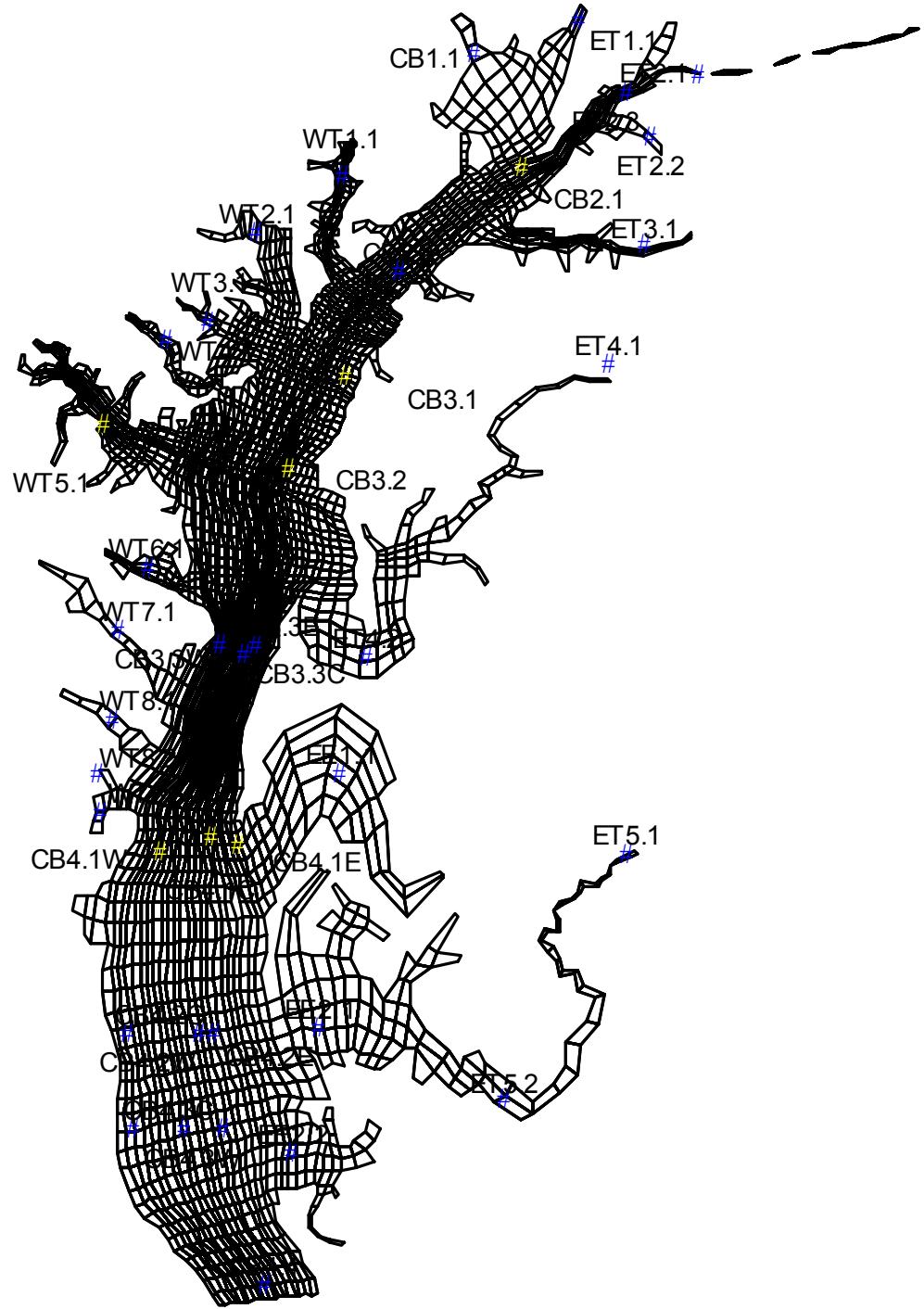
Middle layer circulation



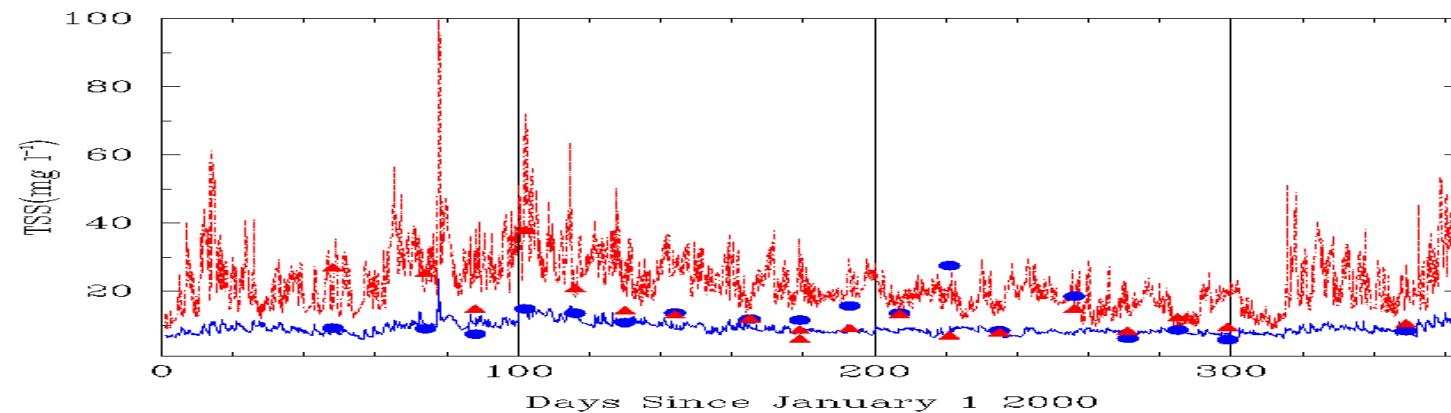
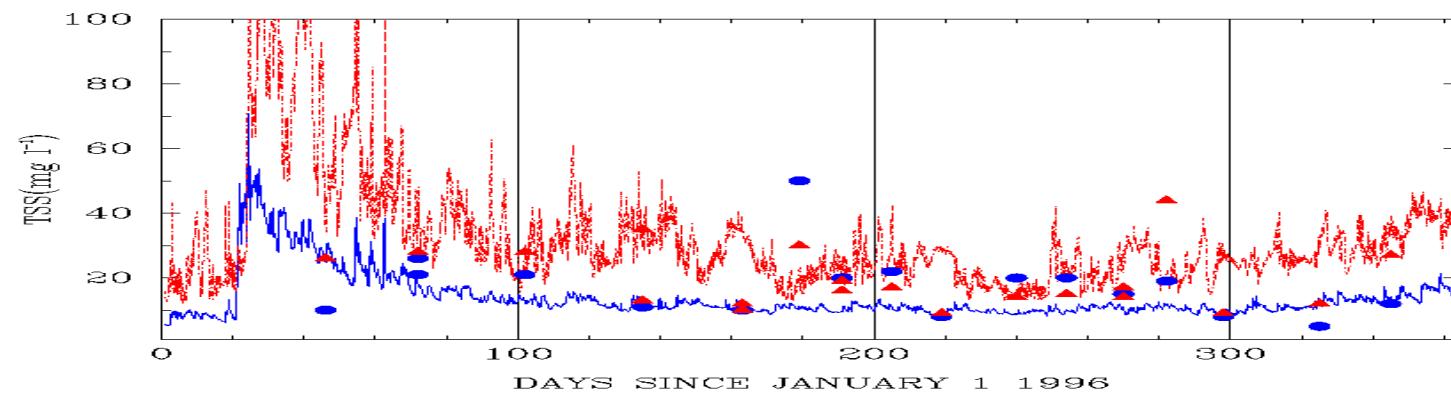
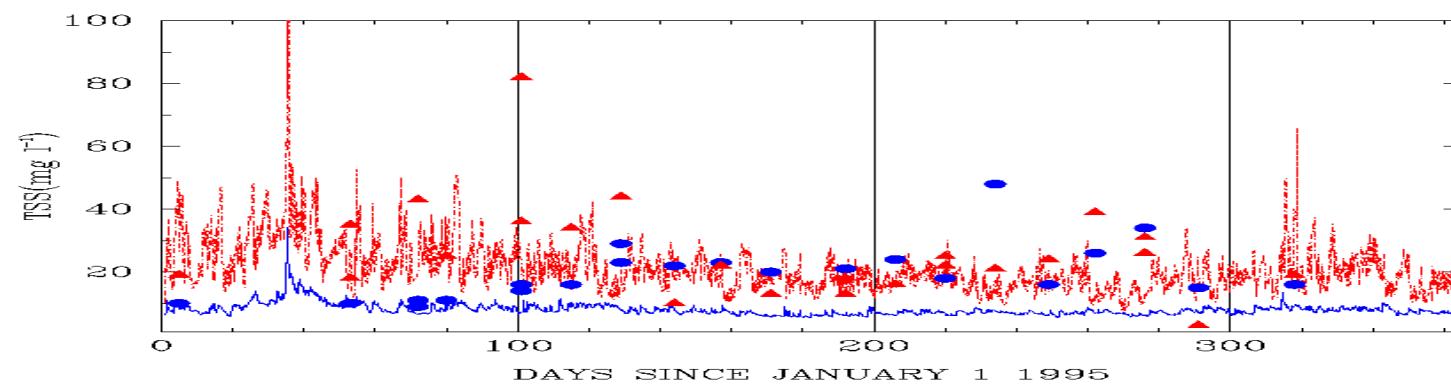
Bottom layer circulation

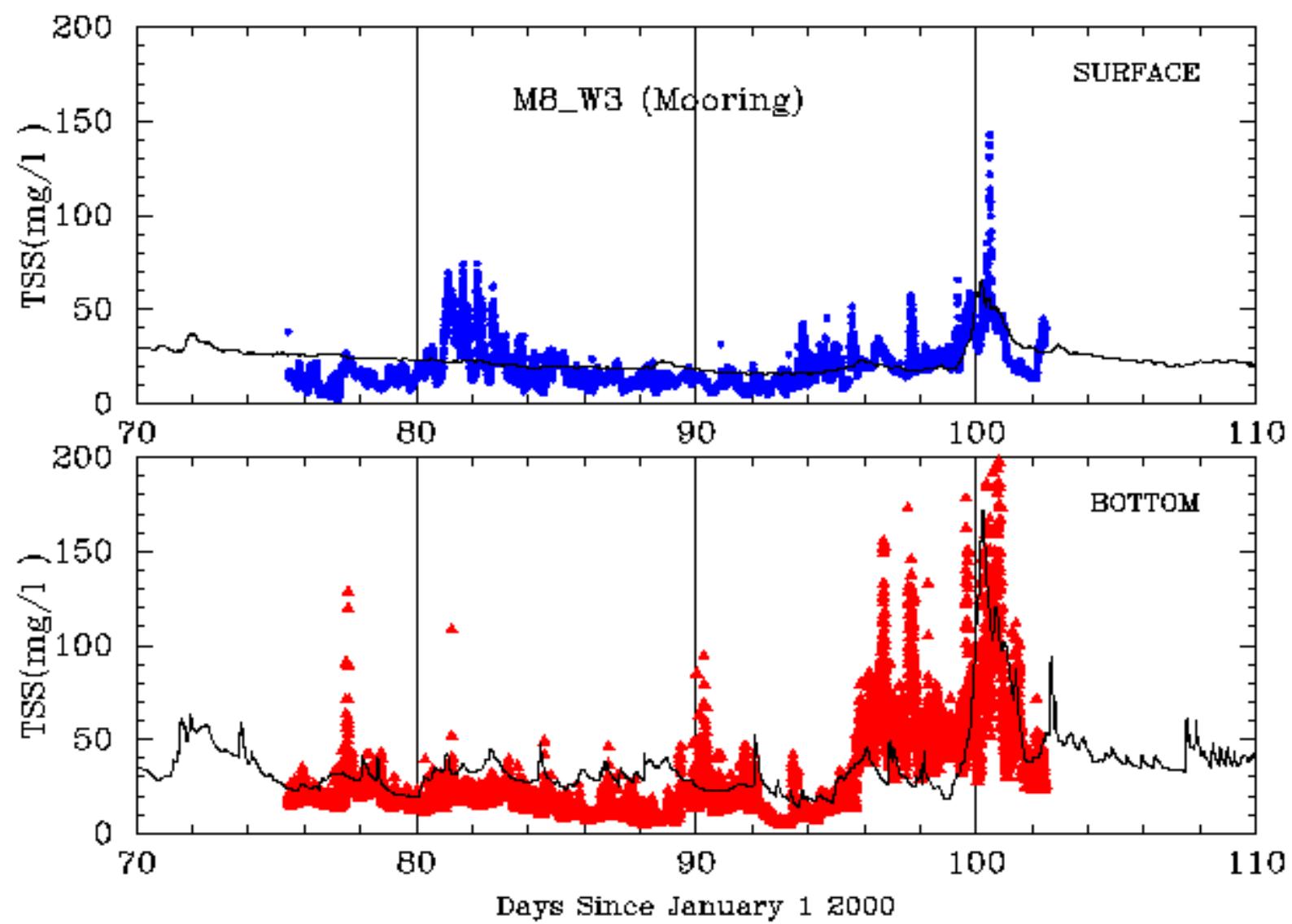
## CH3D-SED basic features

- Three sediment classes ( $3.5, 15, 65 \mu\text{m}$ )
- Concentration dependent settling velocity  
(Arithurai and Krone, 1976)
- Depth dependent erosion formulae in Baltimore Harbor  
(Sanford and Maa, 2001; Lin et al., 2003)



WT5\_1 Baltimore Harbor west

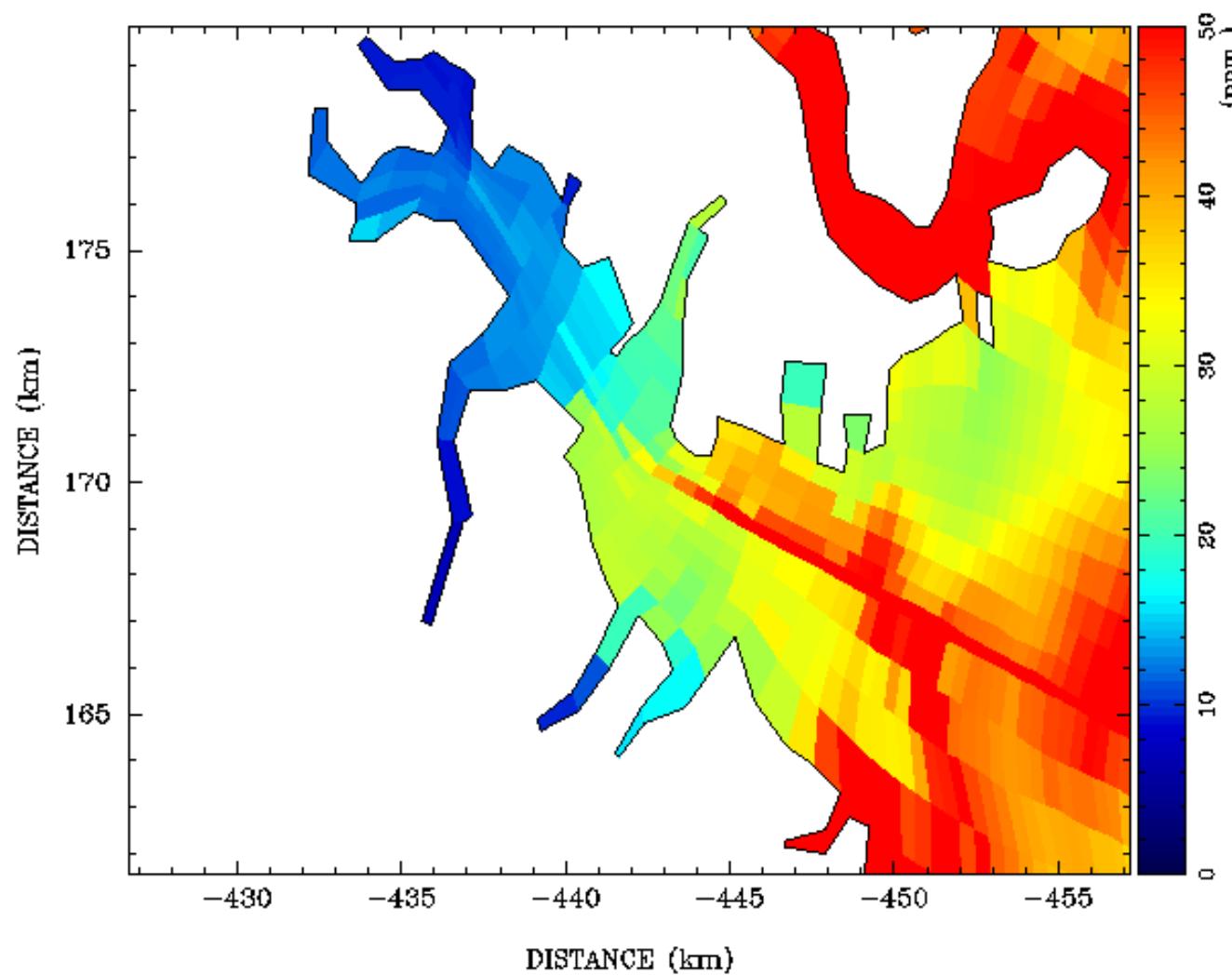






TIME=101.40 J. DAY

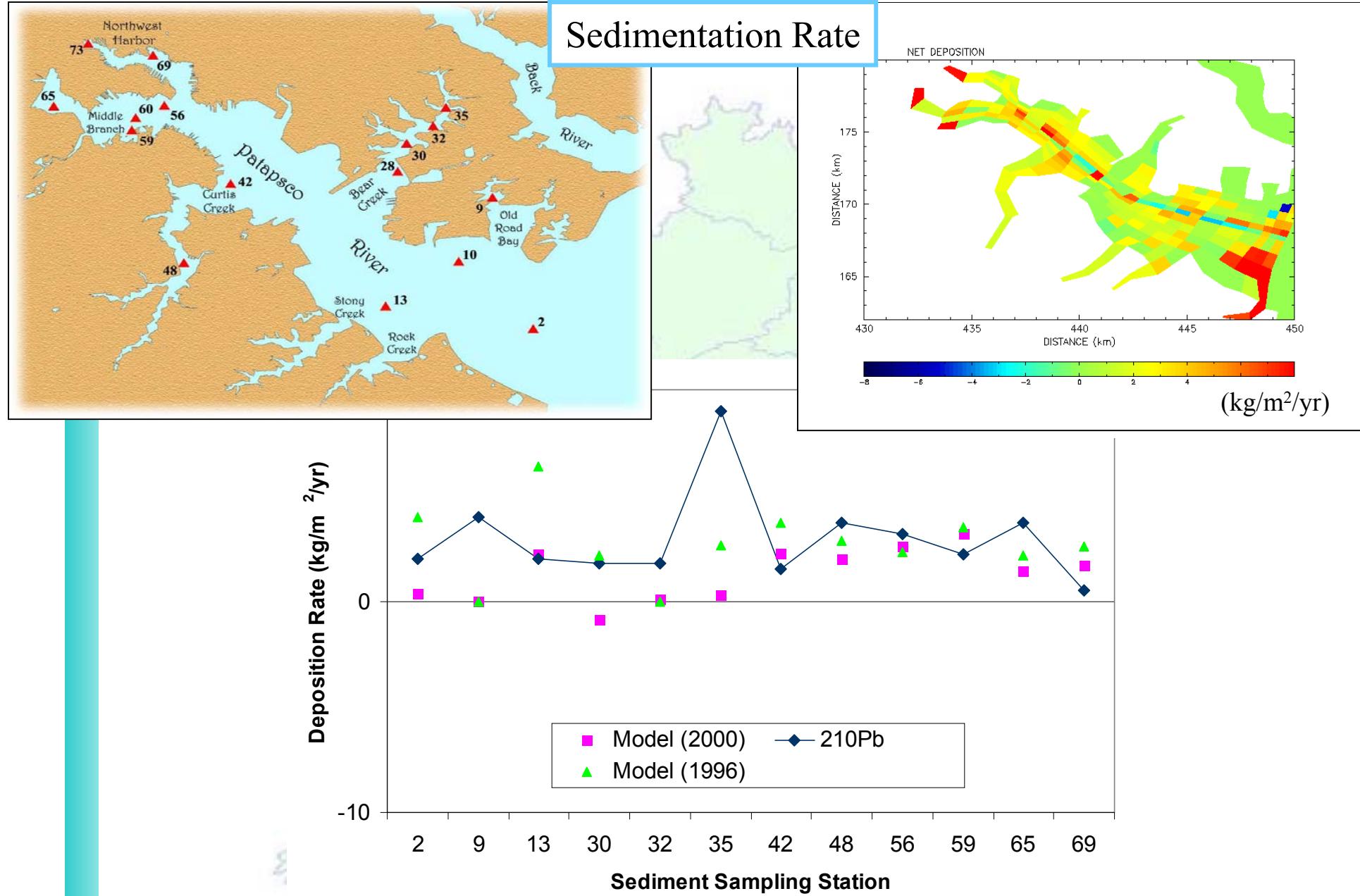
BOTTOM



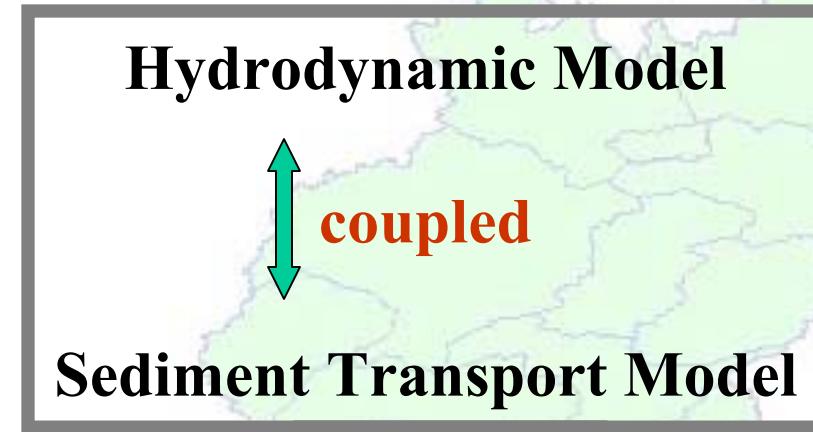
**VIMS**



## Sedimentation Rate



(Field data from Sanford and Cornwell)

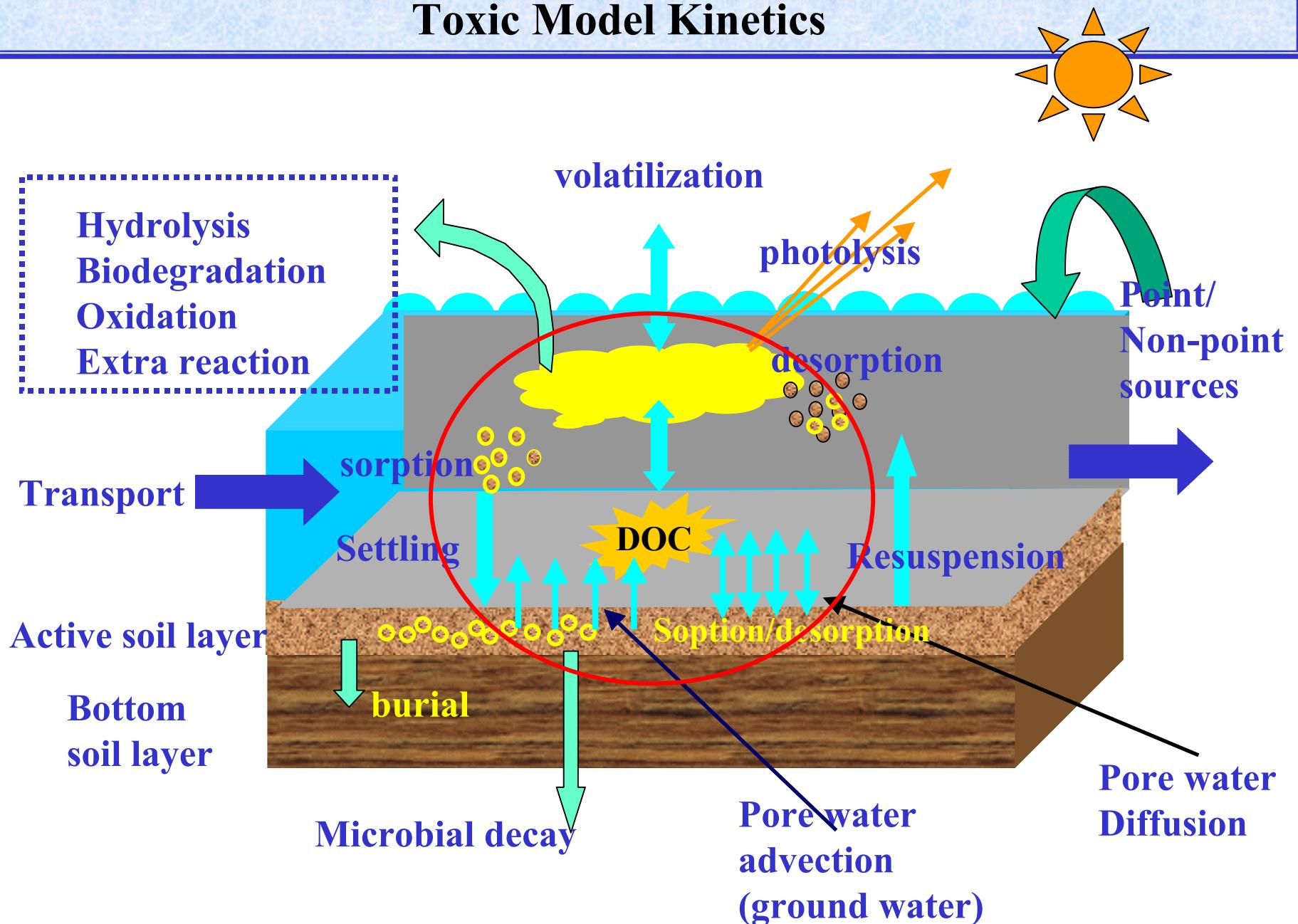


**Interface**

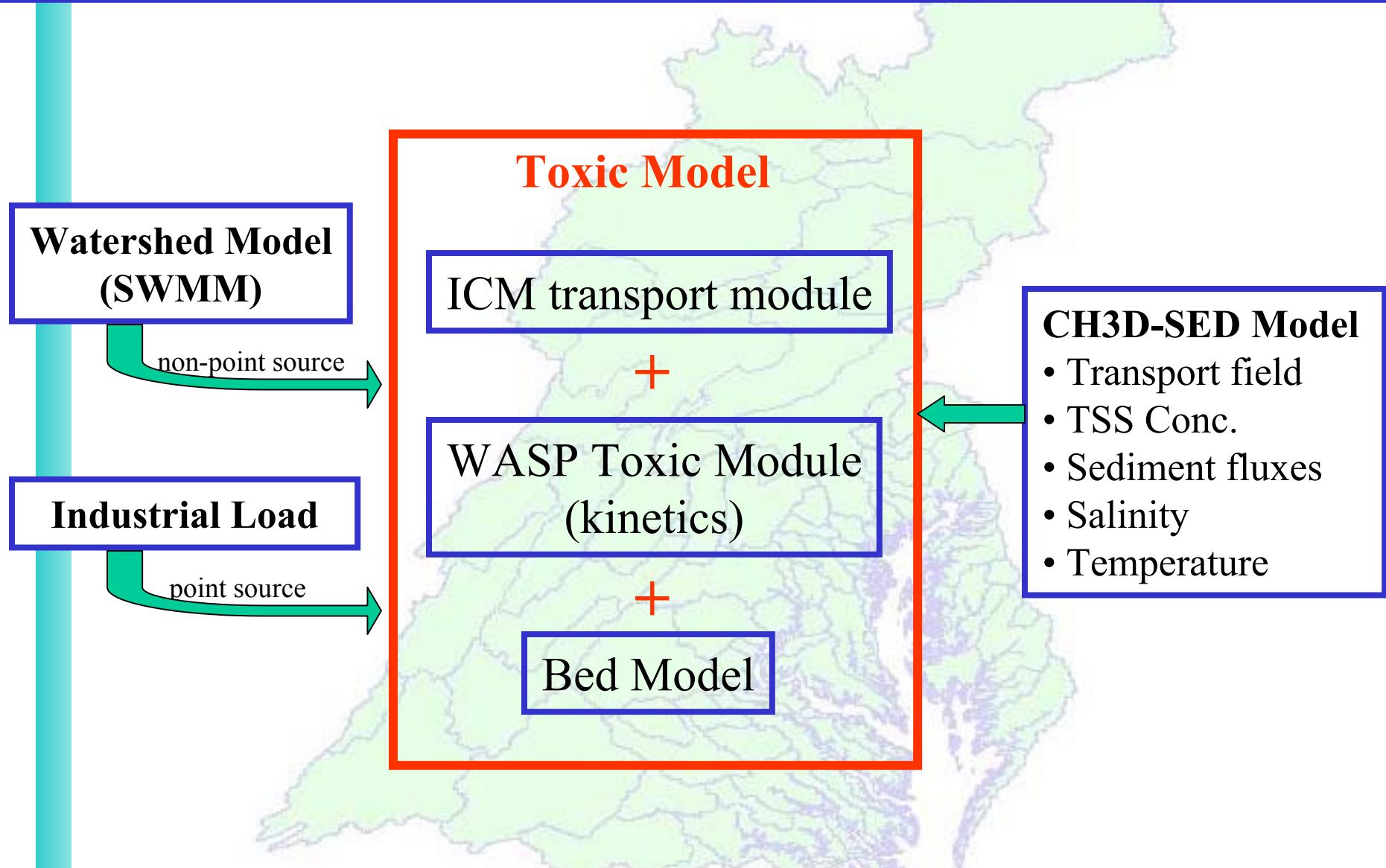
**Interface**

**Toxic Model**

# Toxic Model Kinetics



# CE-QUAL-ICM/TOXI



# EROSION

T = 0



erosion

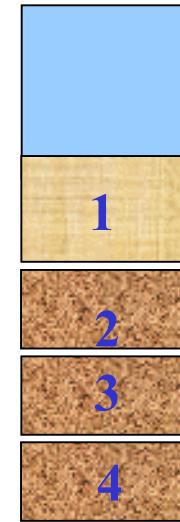


T = 1

combine



Add a new layer



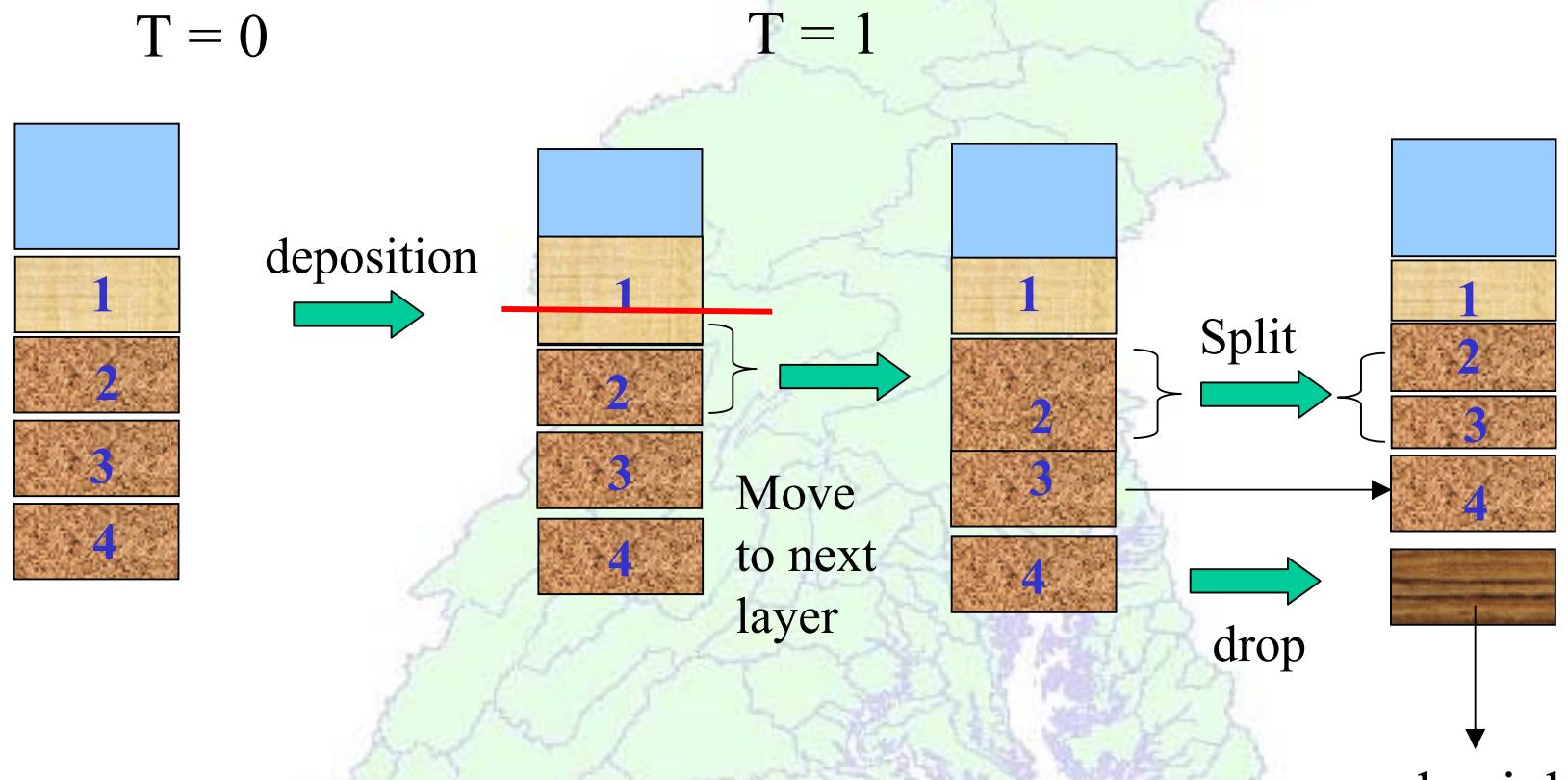
move upward



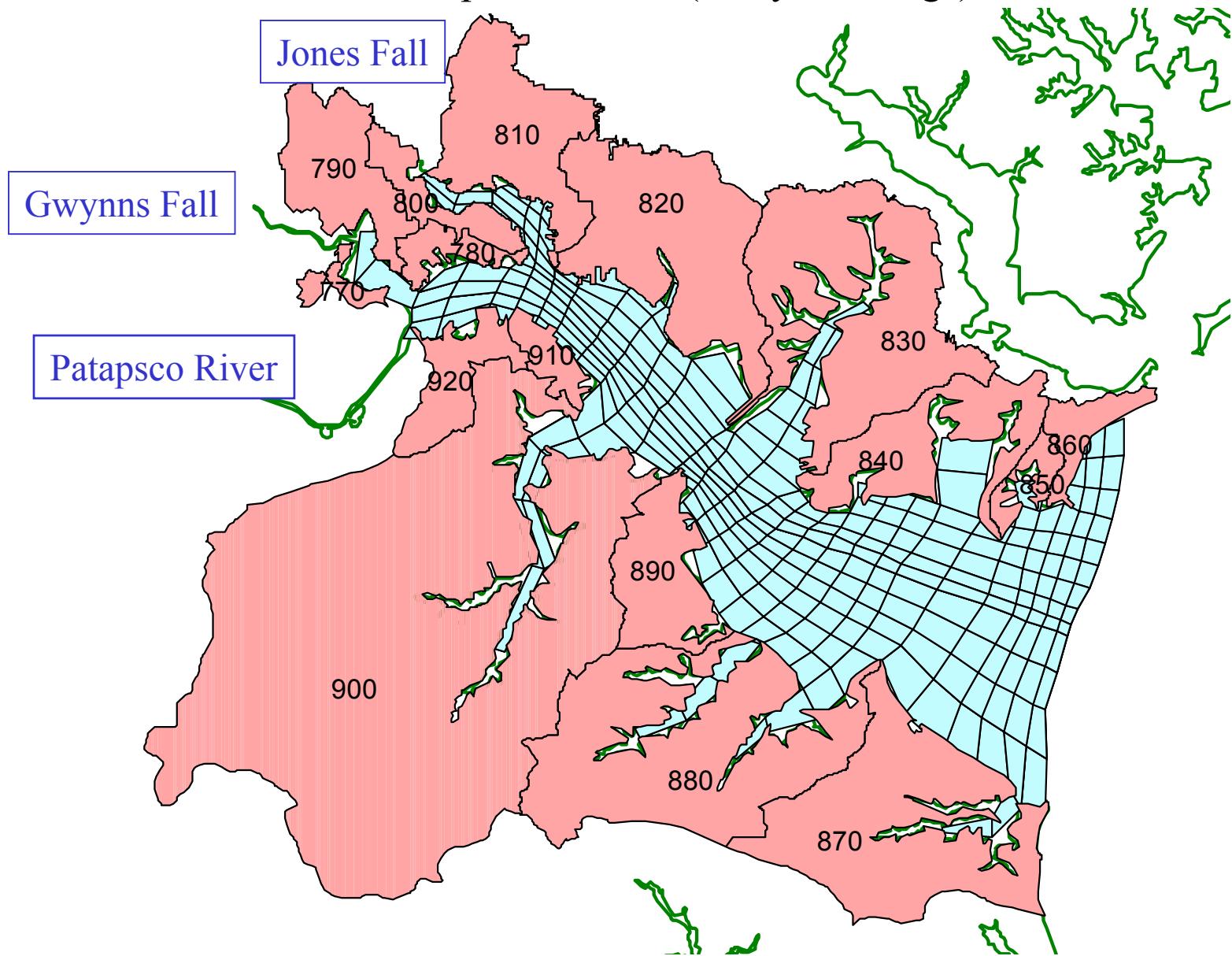
Add a new layer



# DEPOSITION (CONT.)

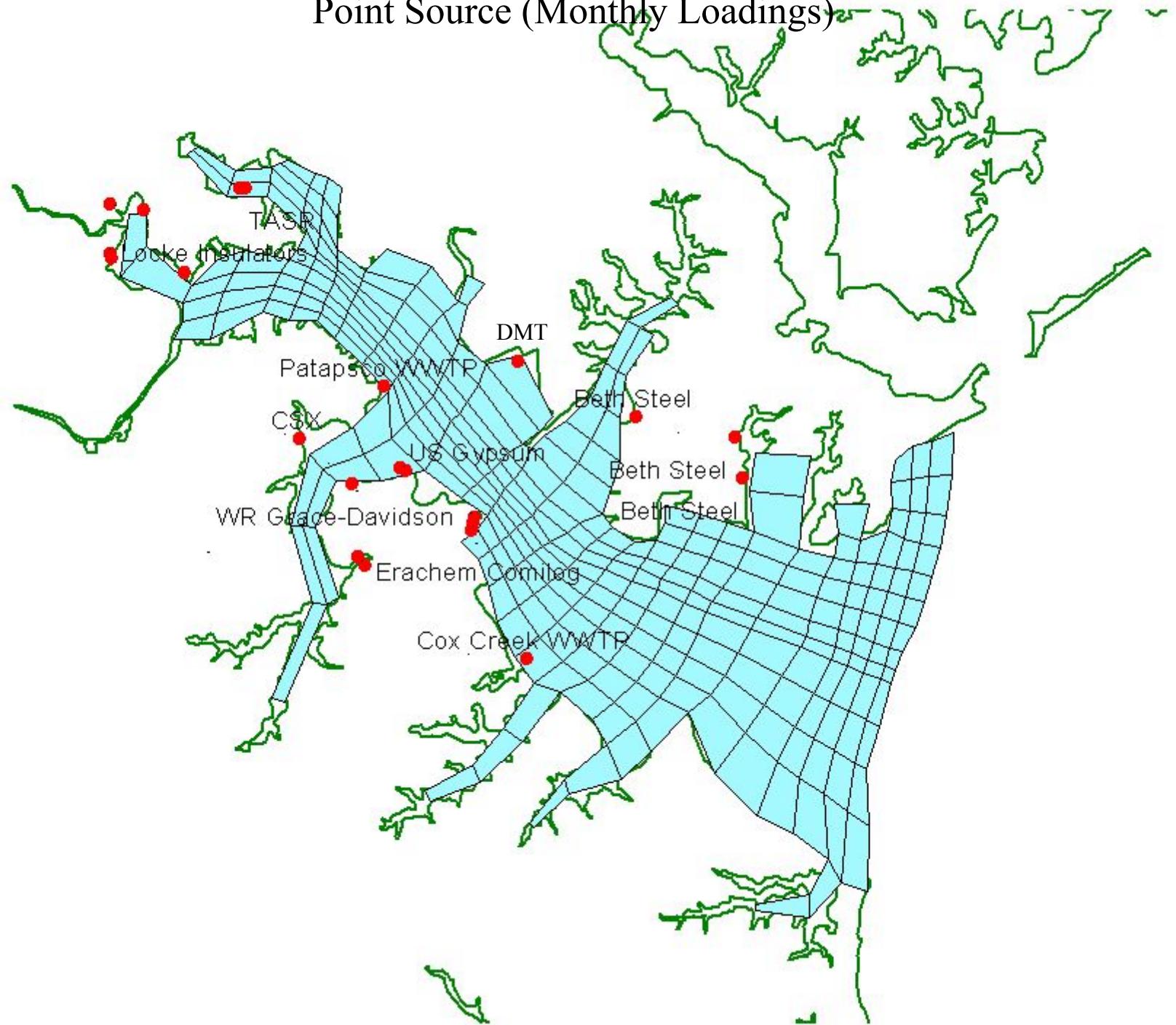


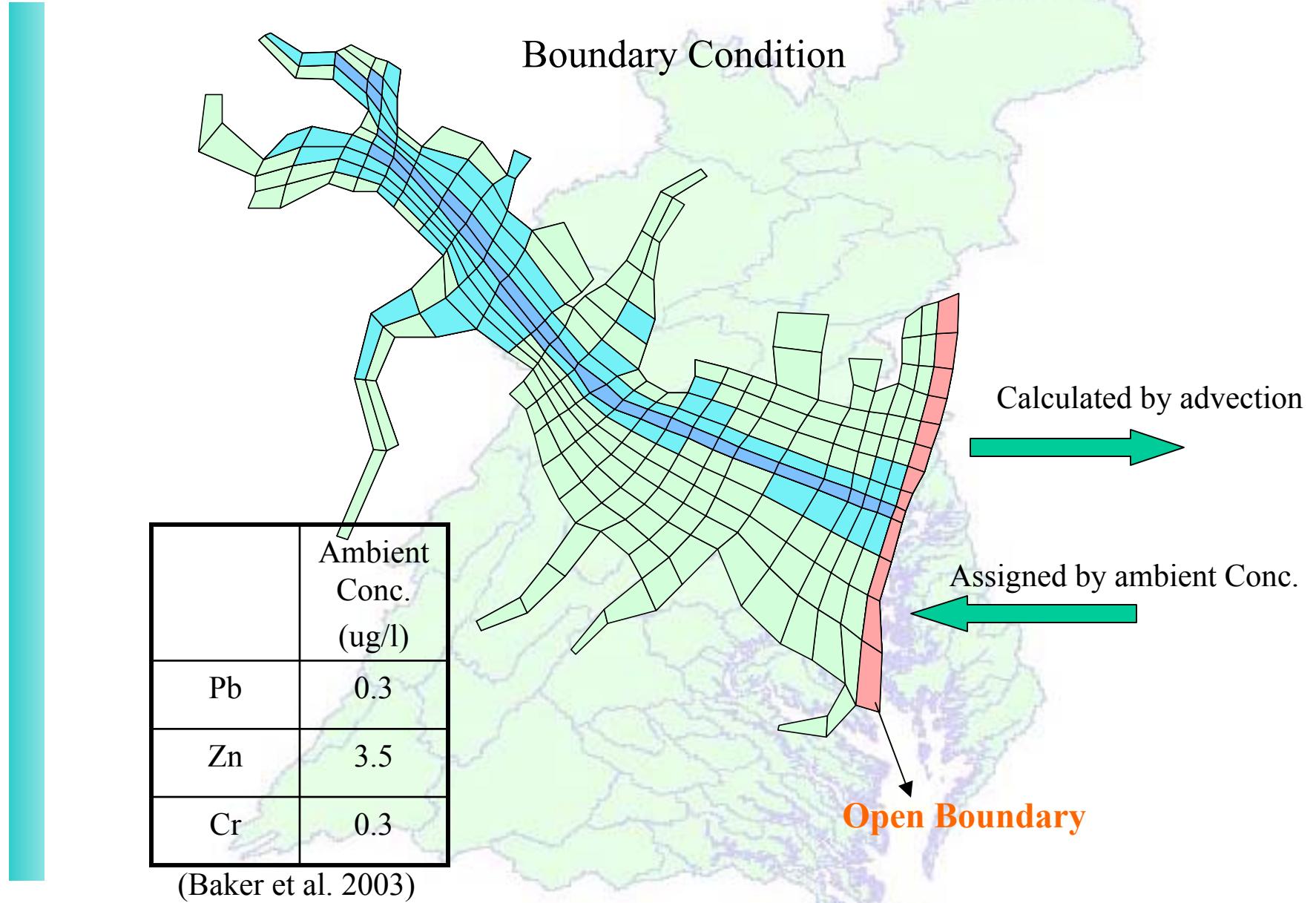
## Nonpoint Source (Daily Loadings)



SWMM model segmentation (MDE)

## Point Source (Monthly Loadings)

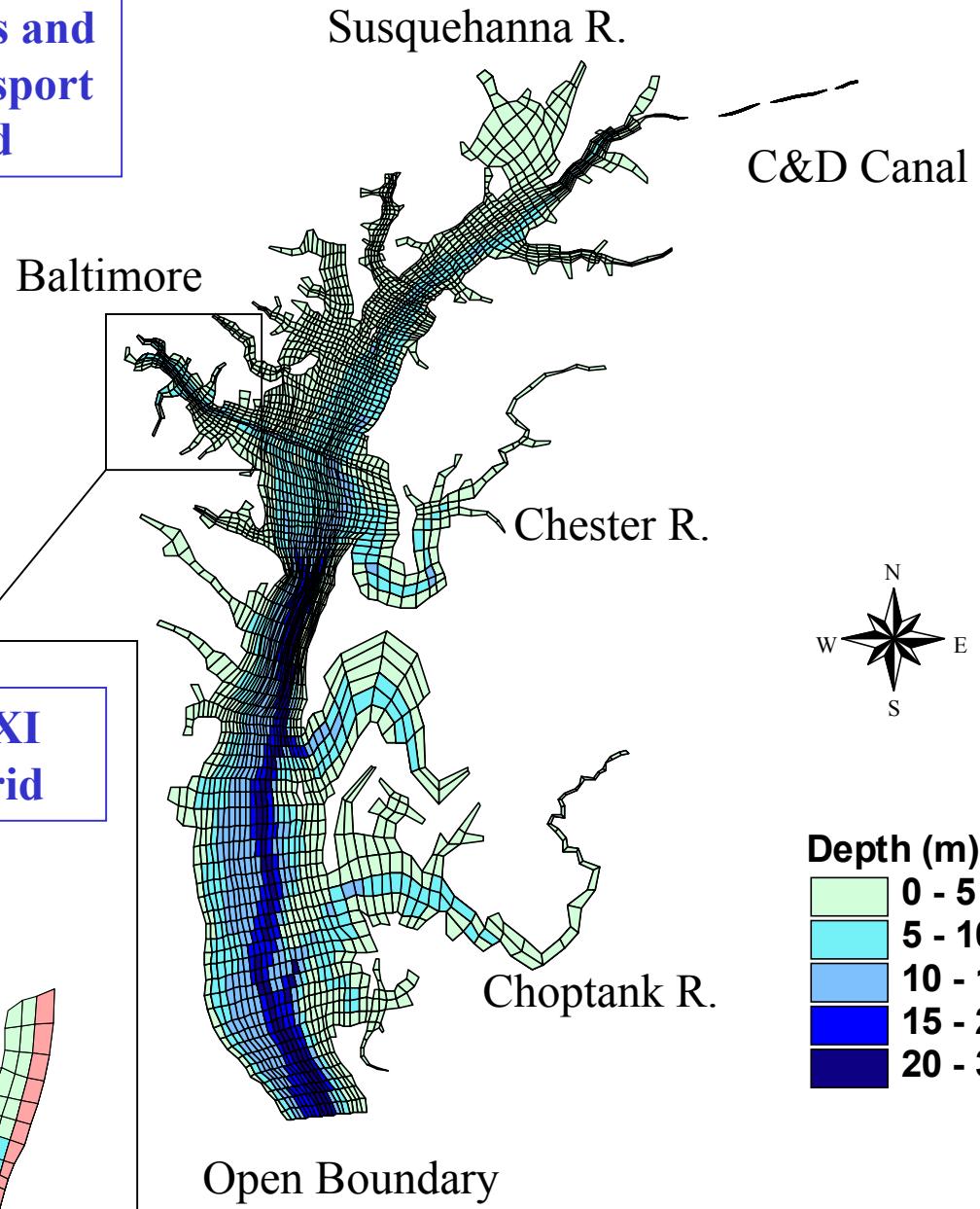




## Basic Parameters used in ICM/TOXI

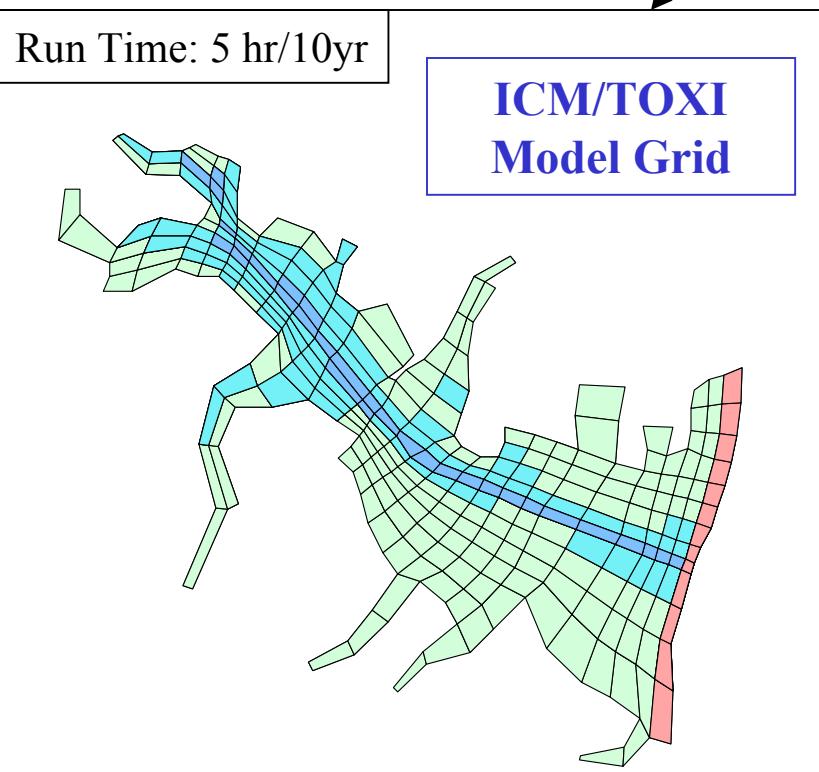
Parameters	Pb	Zn	Cr
Number of bed layers	3	3	3
Surface layer thickness (cm)	3	3	3
Subsurface layer thickness (cm)	6	6	6
Partition coefficient ( $10^4$ l/kg)	5.98	4.57	21.70
Surface Porosity	0.41-0.93	0.41-0.93	0.41-0.93
Reference Porosity	0.65	0.65	0.65
Benthic Diffusivity (cm <sup>2</sup> /s)	1e-5	1e-5	1e-5
Hydro and Sediment update frequency (hr)	1	1	1
Total boxes	1072	1072	1072

**Hydrodynamics and  
Sediment Transport  
Model Grid**

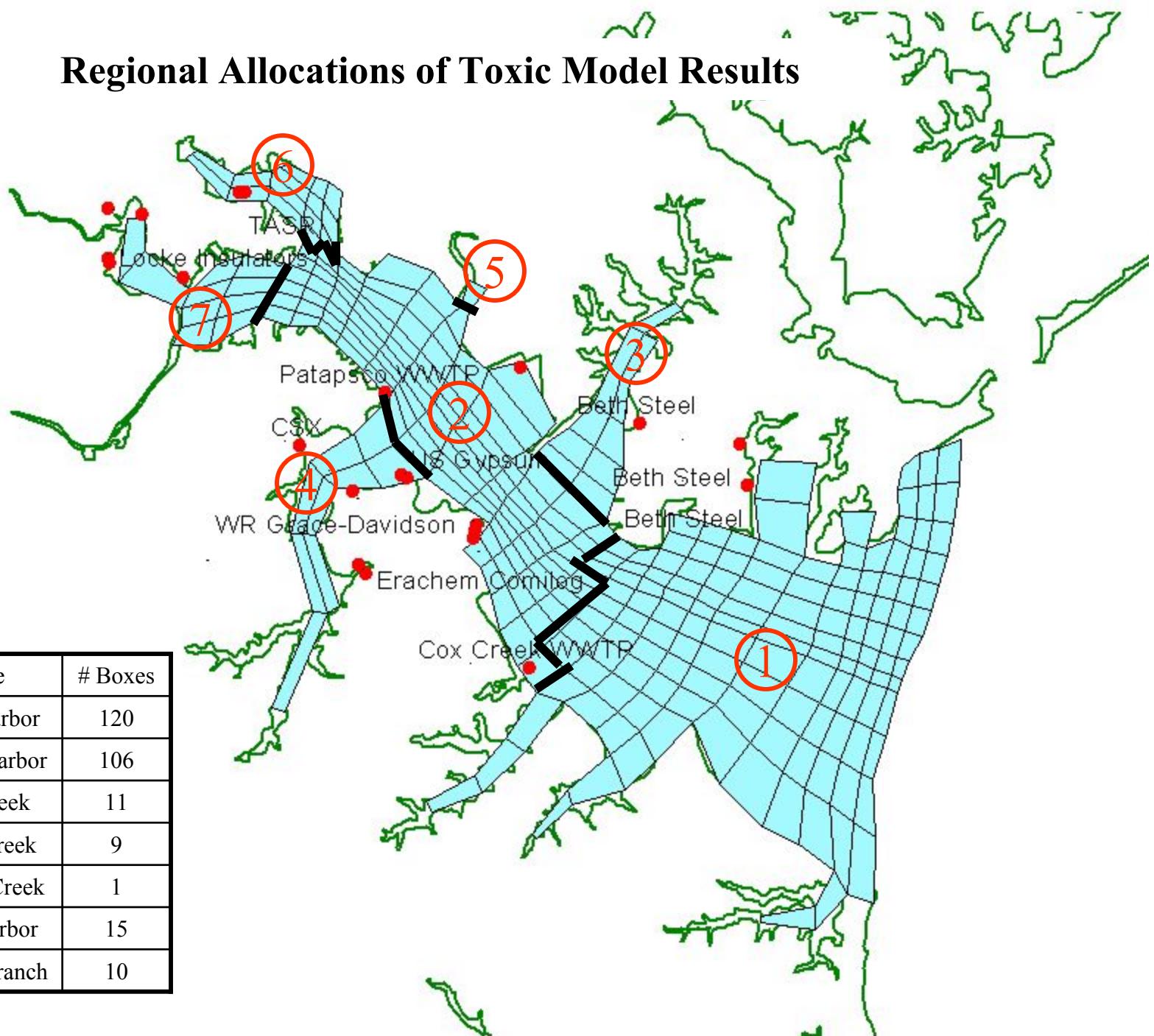


Run Time: 5 hr/10yr

**ICM/TOXI  
Model Grid**



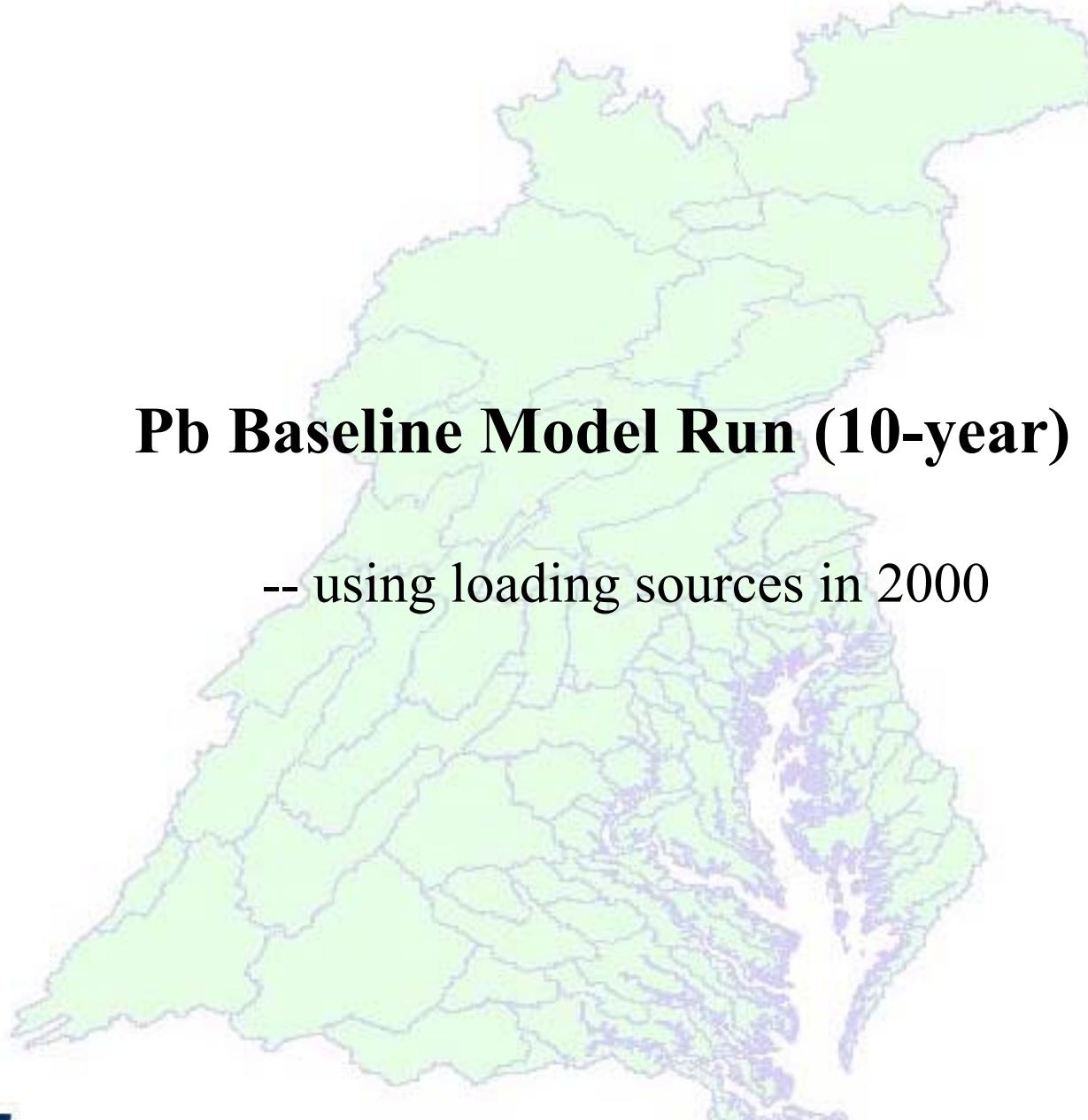
## Regional Allocations of Toxic Model Results



Region	Name	# Boxes
1	Outer Harbor	120
2	Middle Harbor	106
3	Bear Creek	11
4	Curtis Creek	9
5	Colgate Creek	1
6	Inner Harbor	15
7	Middle Branch	10

# Contents

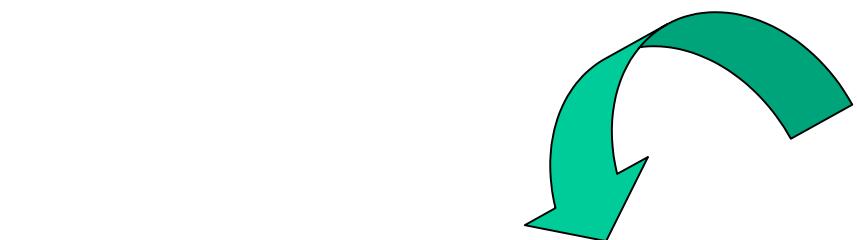
- **Introduction**
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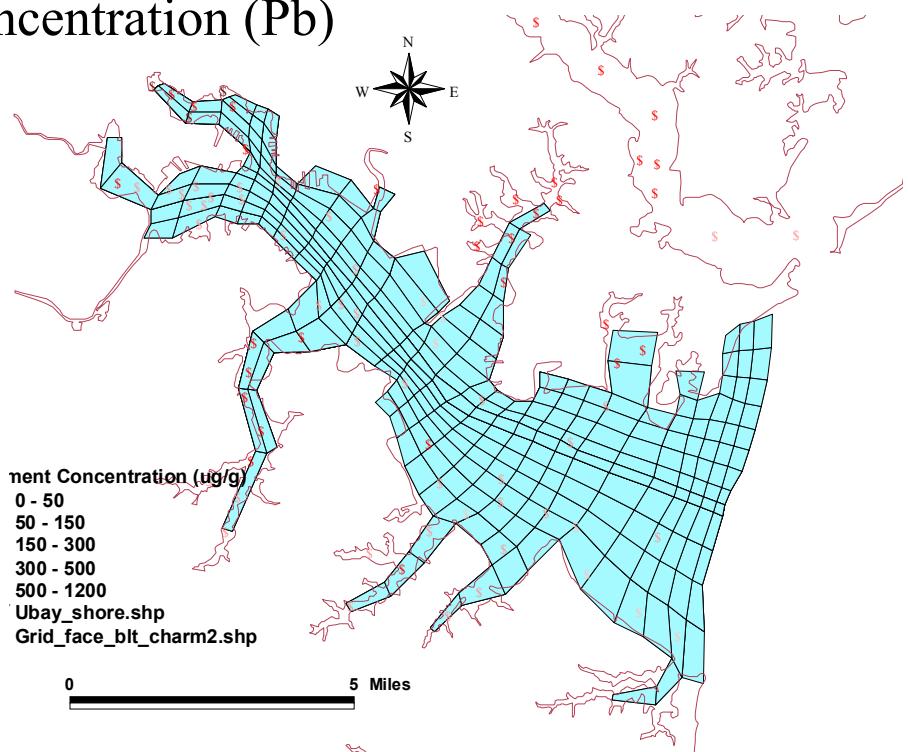
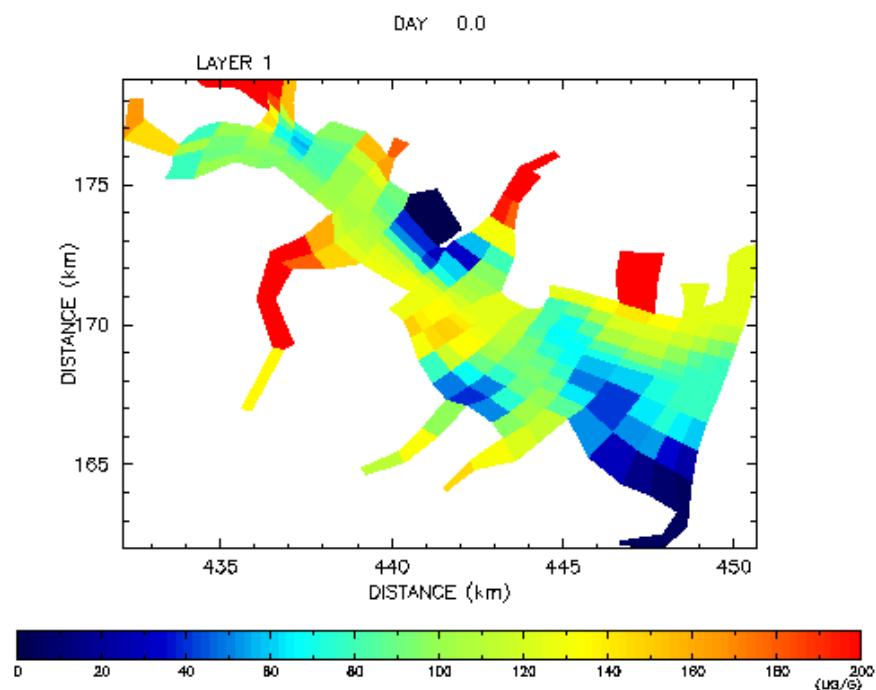
## Pb Baseline Model Run (10-year)

-- using loading sources in 2000

# Initial Sediment Concentration (Pb)



Model Initial Condition

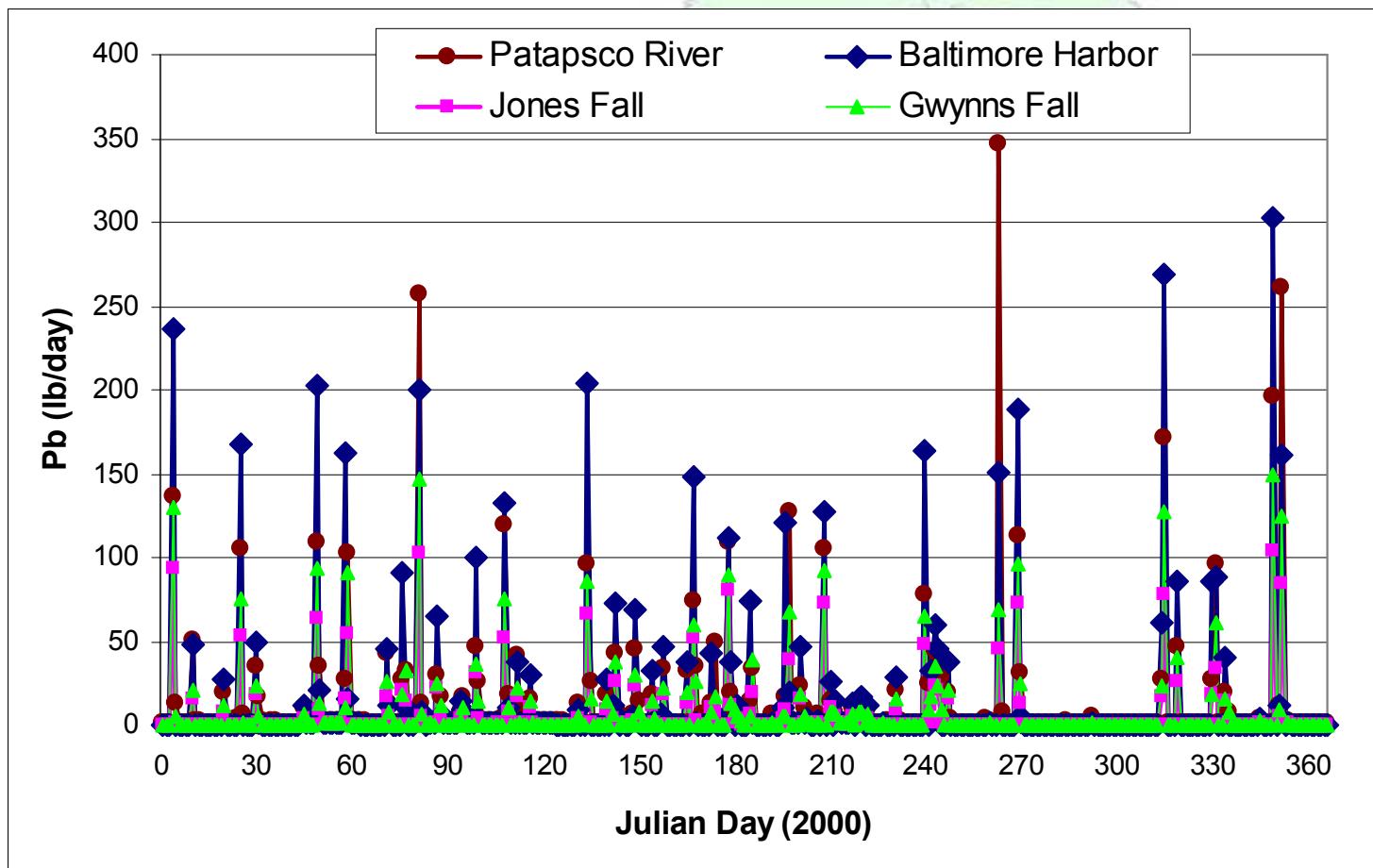


1996 Sediment Mapping Survey (Baker et al., 1997)

## Reference:

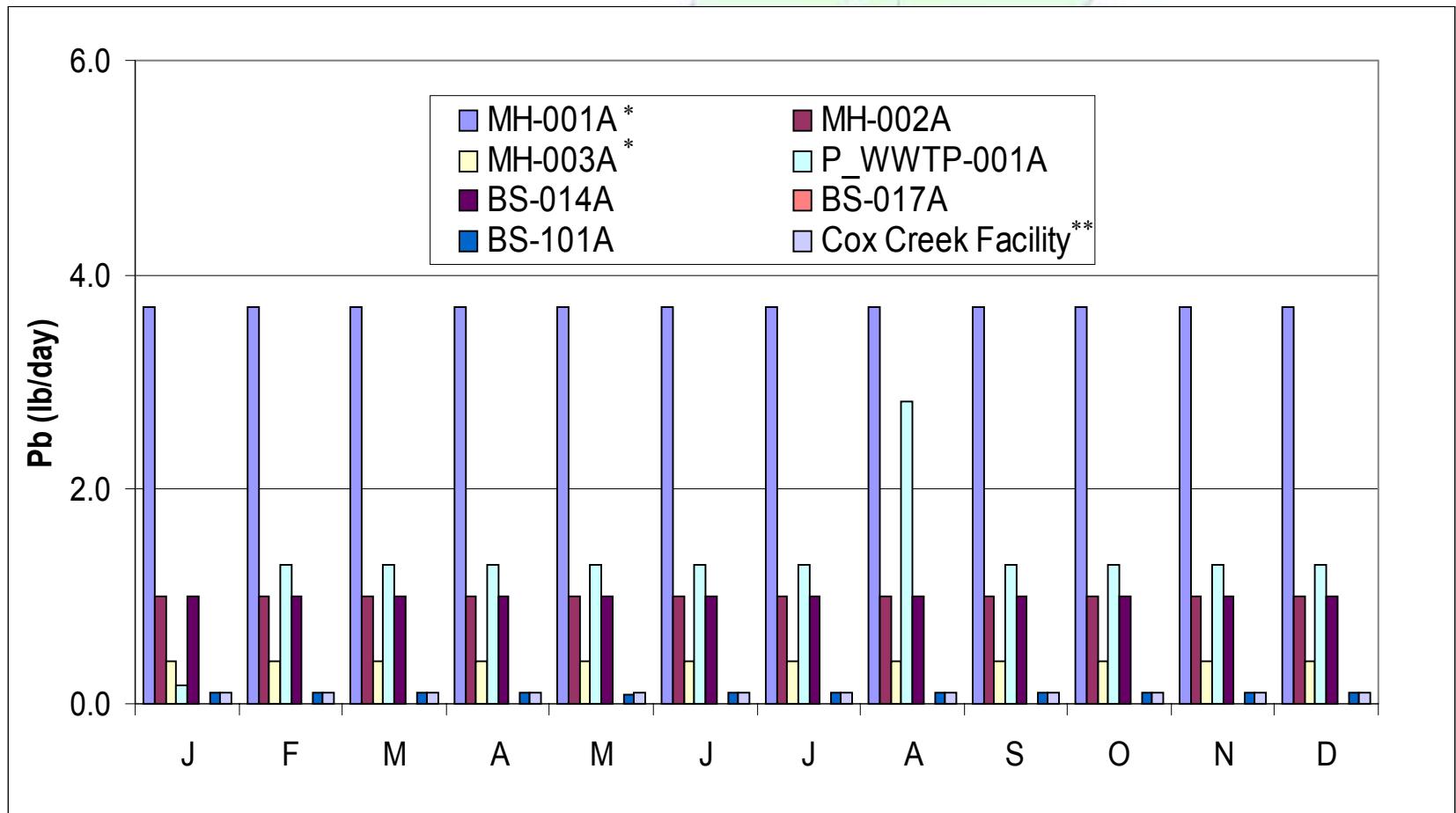
Baker J., R. Mason, J. Cornwell, J. Ashley, J. Halka and J. Hill, 1997, Spatial mapping of sedimentary contaminants in the Baltimore Harbor / Patapsco River/Back River System, Final Report submitted to Maryland Department of the Environment

## Pb non-point source loadings



Total: 6450.2 kg

# Pb point source loadings

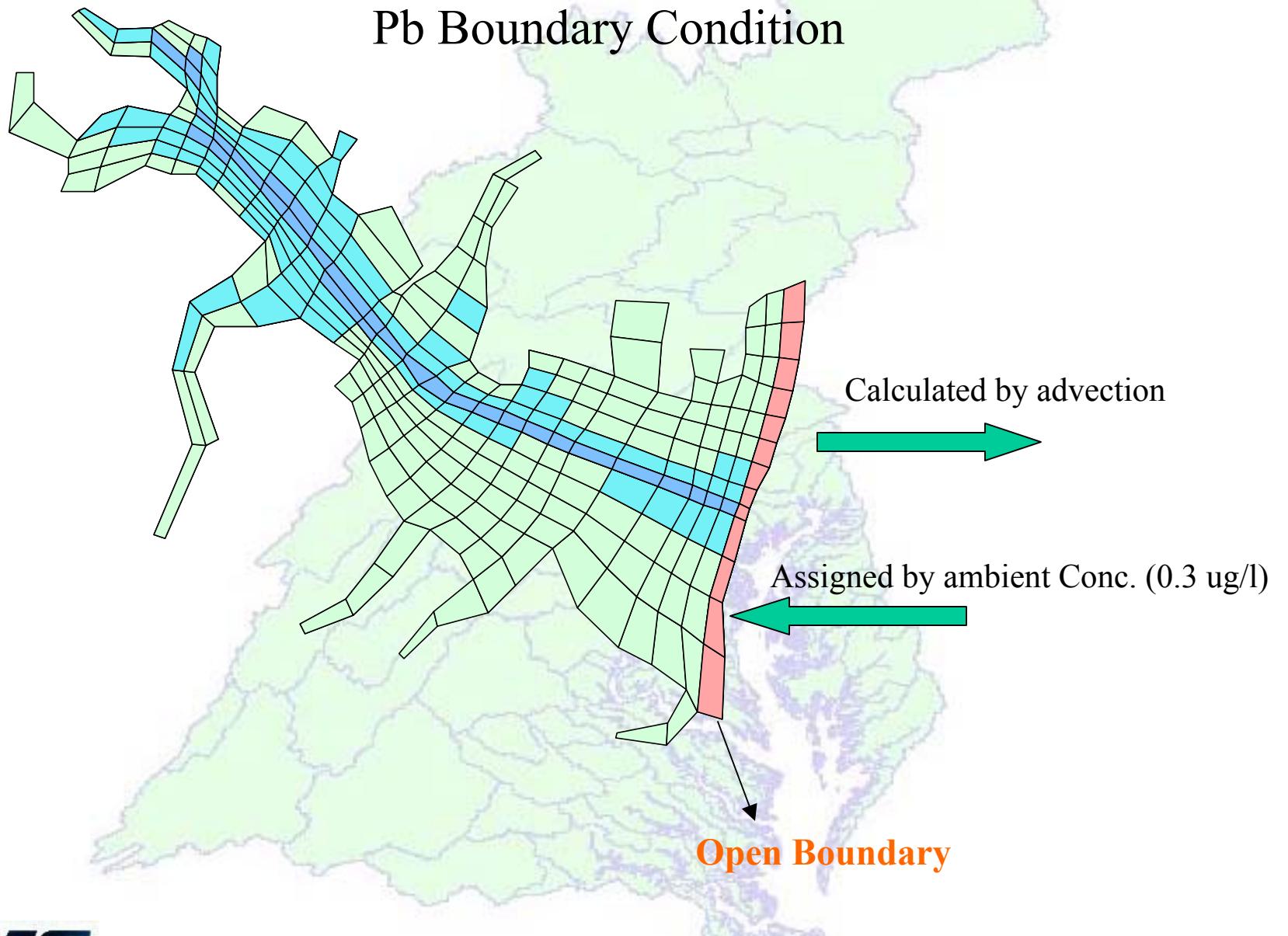


\* Mean values used for Millennium-Hawkins and Beth-Steel

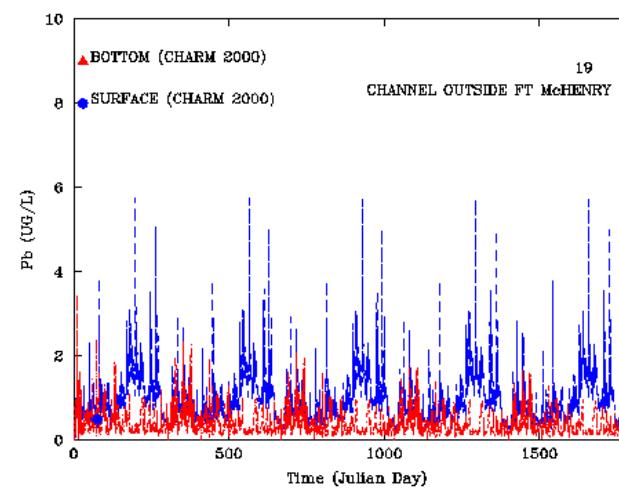
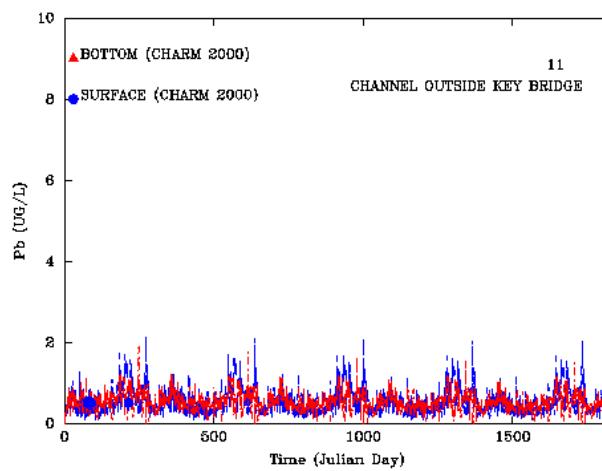
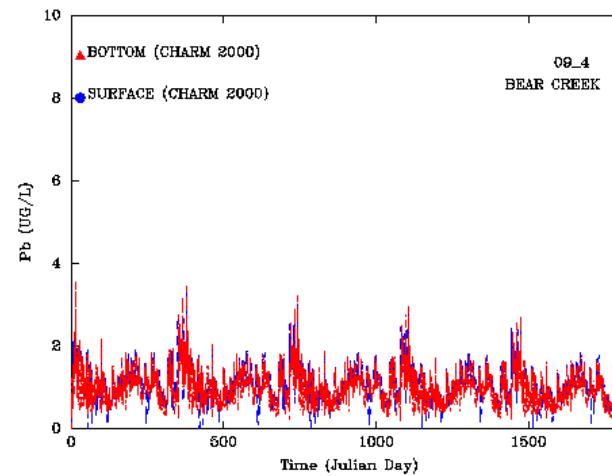
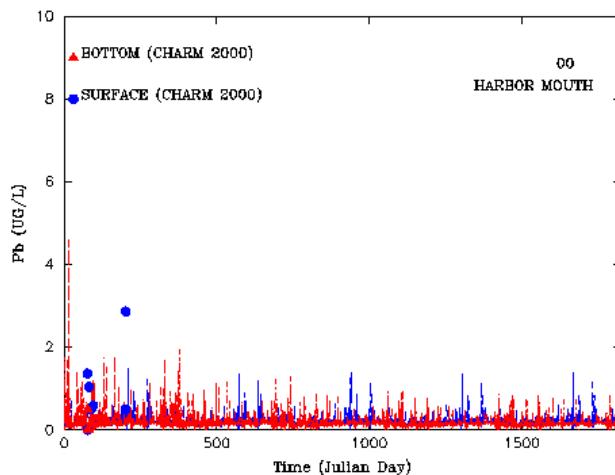
\*\* included only in scenario model runs

Total: 1229.2 kg

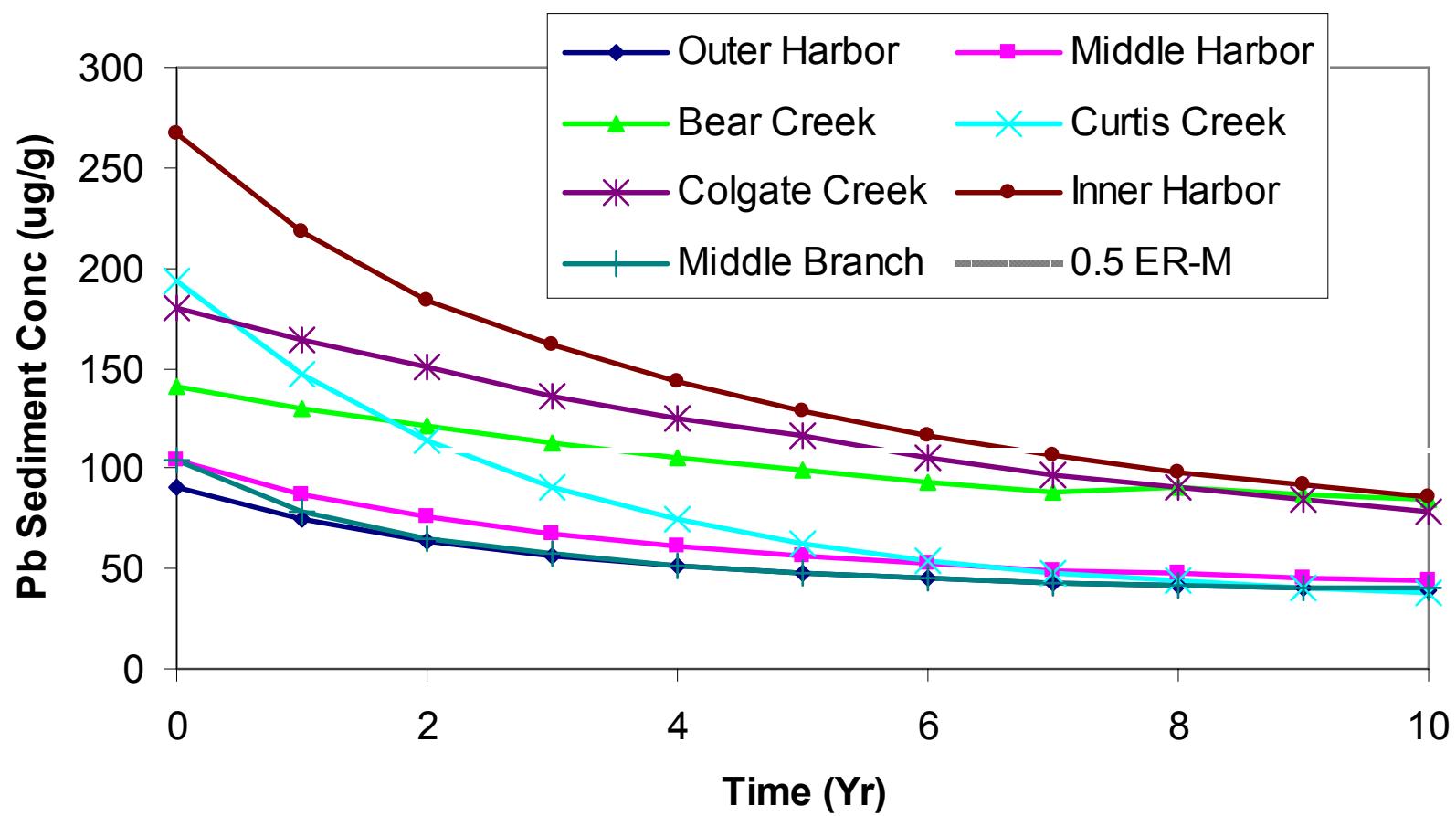
## Pb Boundary Condition



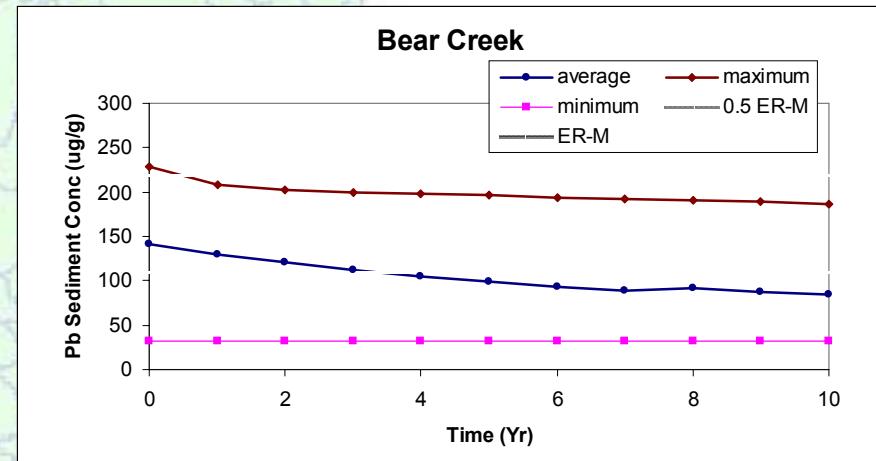
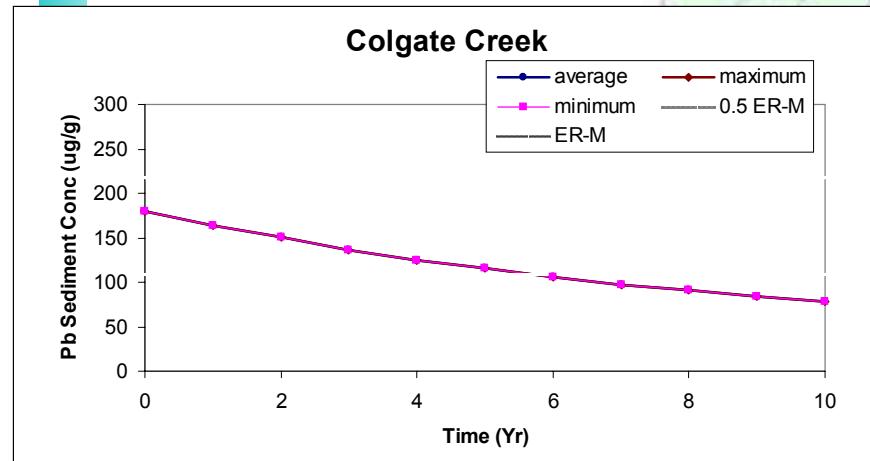
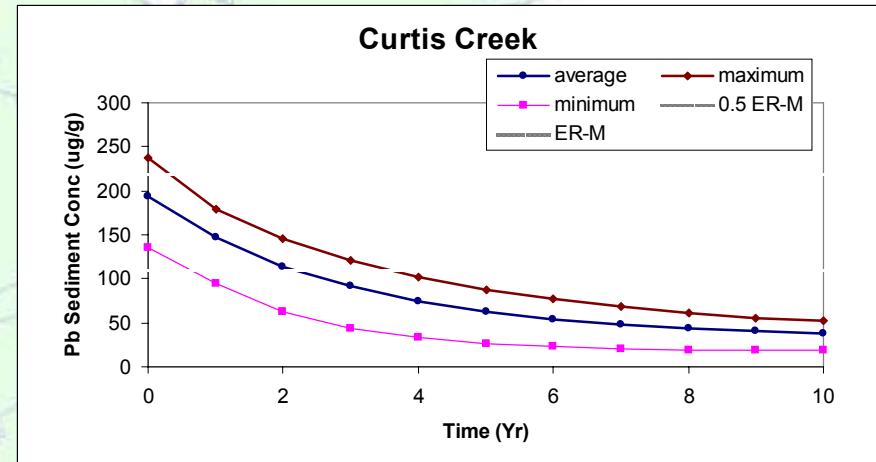
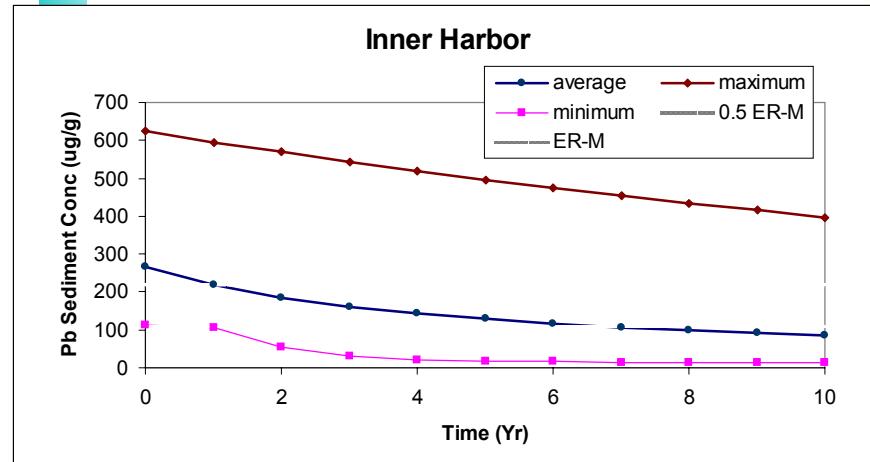
# Pb Water Column Concentration



# Pb Sediment Concentration (time series)



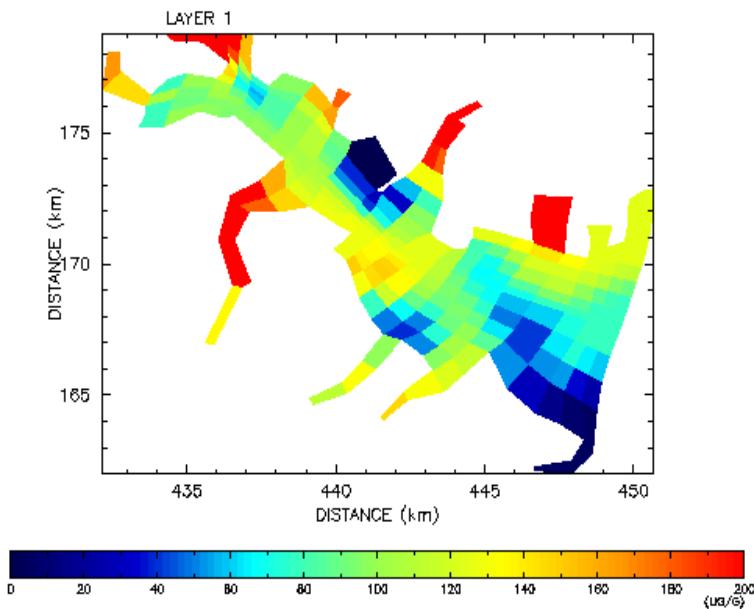
# Pb Sediment Concentration (time series)



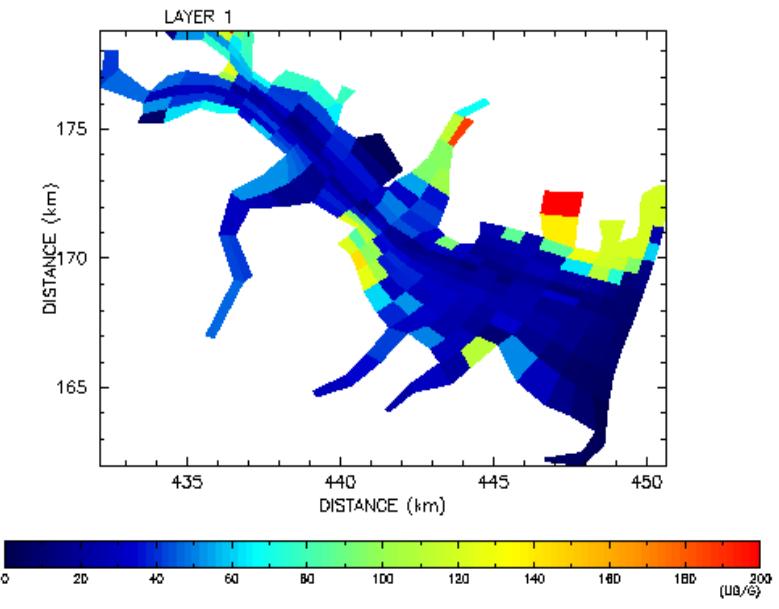
# Pb Sediment Concentration (spatial distribution)



Initial Condition

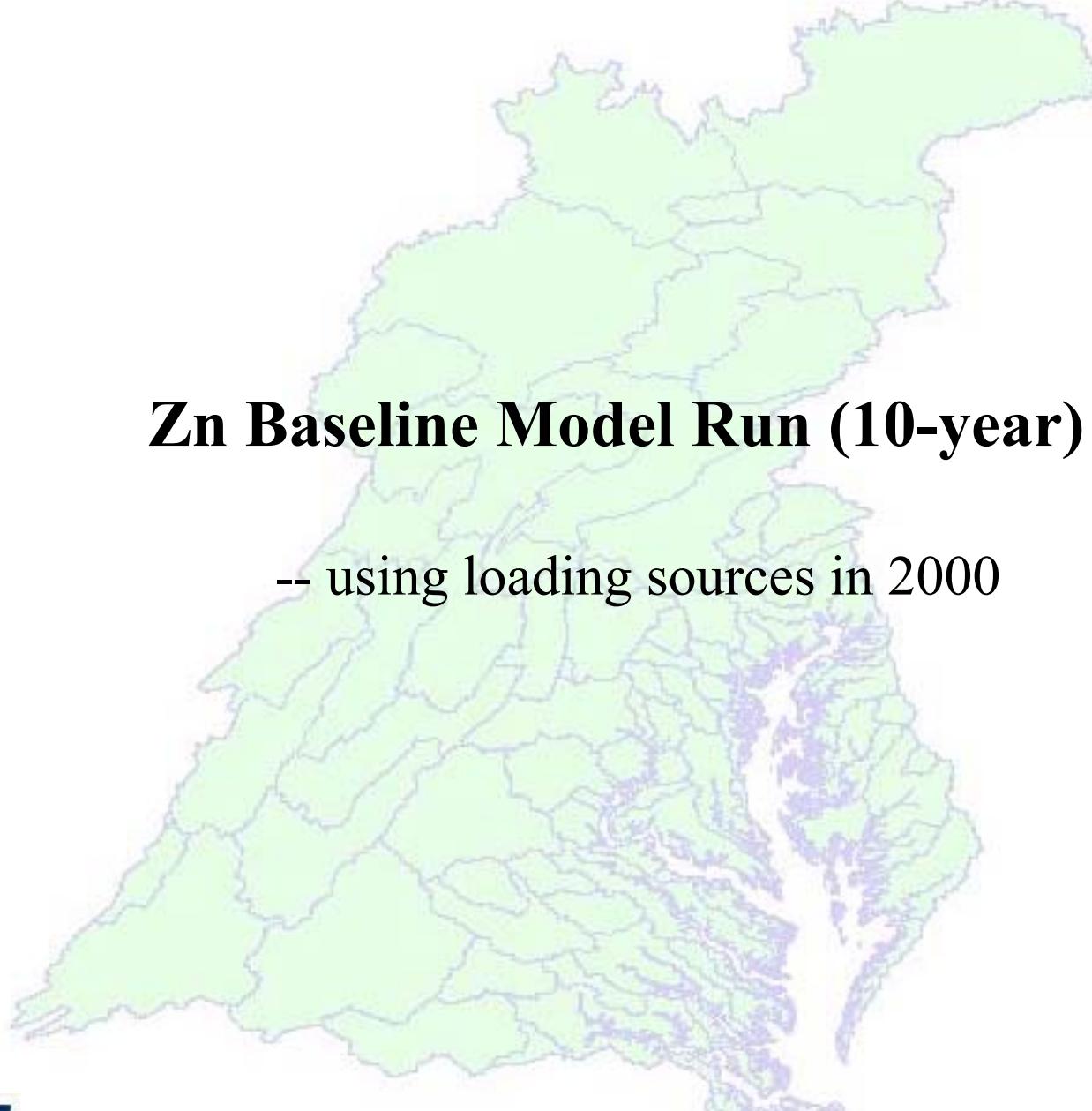


After 10 Year



## Pb Sediment Concentration Changes in Baseline Model Run

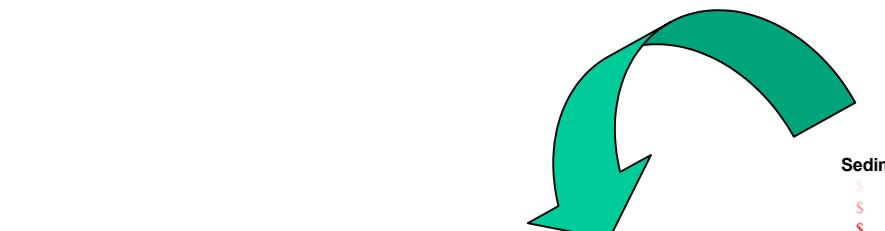
	Outer Harbor	Middle Harbor	Bear Creek	Curtis Creek	Colgate Creek	Inner Harbor	Middle Branch
Average	-52.2 (-57%)	-59.8 (-58%)	-56.9 (-40%)	-155.1 (-80%)	-101.2 (-56%)	-181.4 (-68%)	-63.7 (-61%)
Maximum	-8.0 (-3%)	-19.3 (-12%)	-40.9 (-18%)	-185.3 (-78%)	-101.2 (-56%)	-225.5 (-36%)	-104.8 (-63%)
Minimum	-4.0 (72%)	2.34 (225%)	0.21 (1%)	-117.7 (-87%)	-101.2 (-56%)	-98.1 (-87%)	-70.8 (90%)



## Zn Baseline Model Run (10-year)

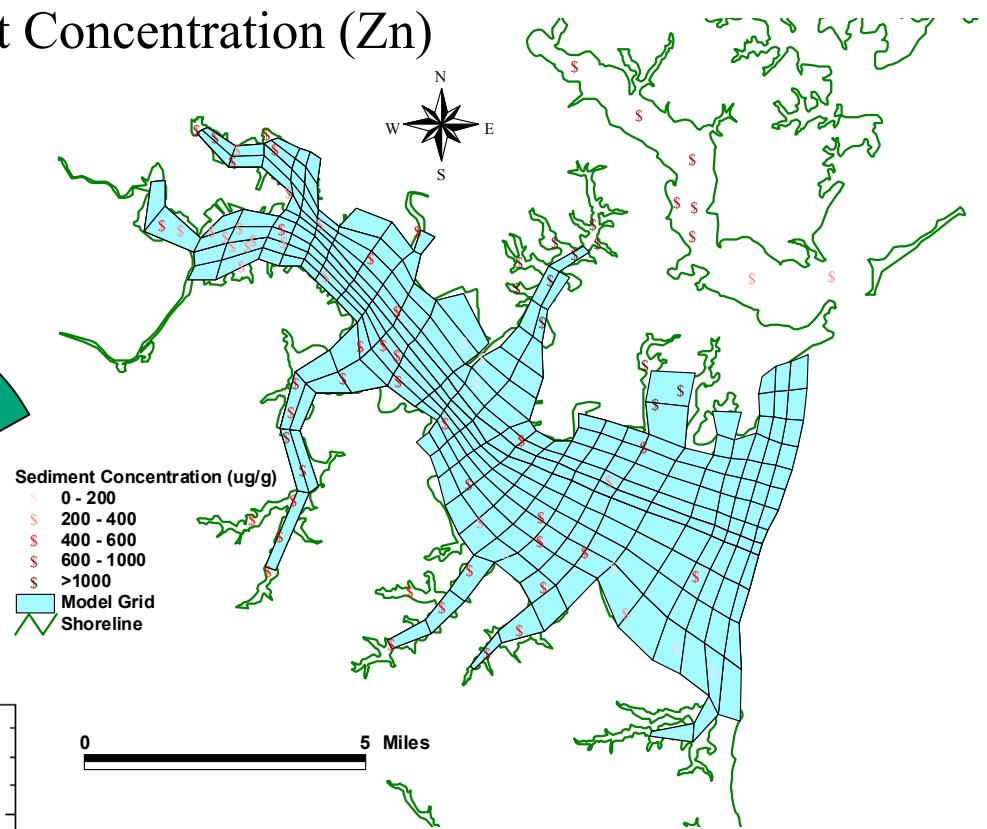
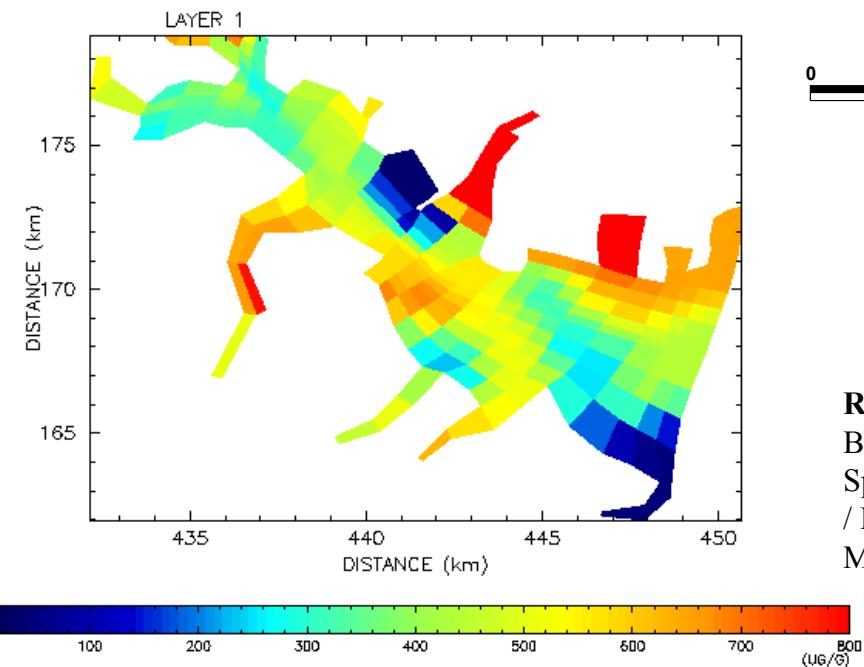
-- using loading sources in 2000

# Initial Sediment Concentration (Zn)



Model Initial Condition

DAY 0.0

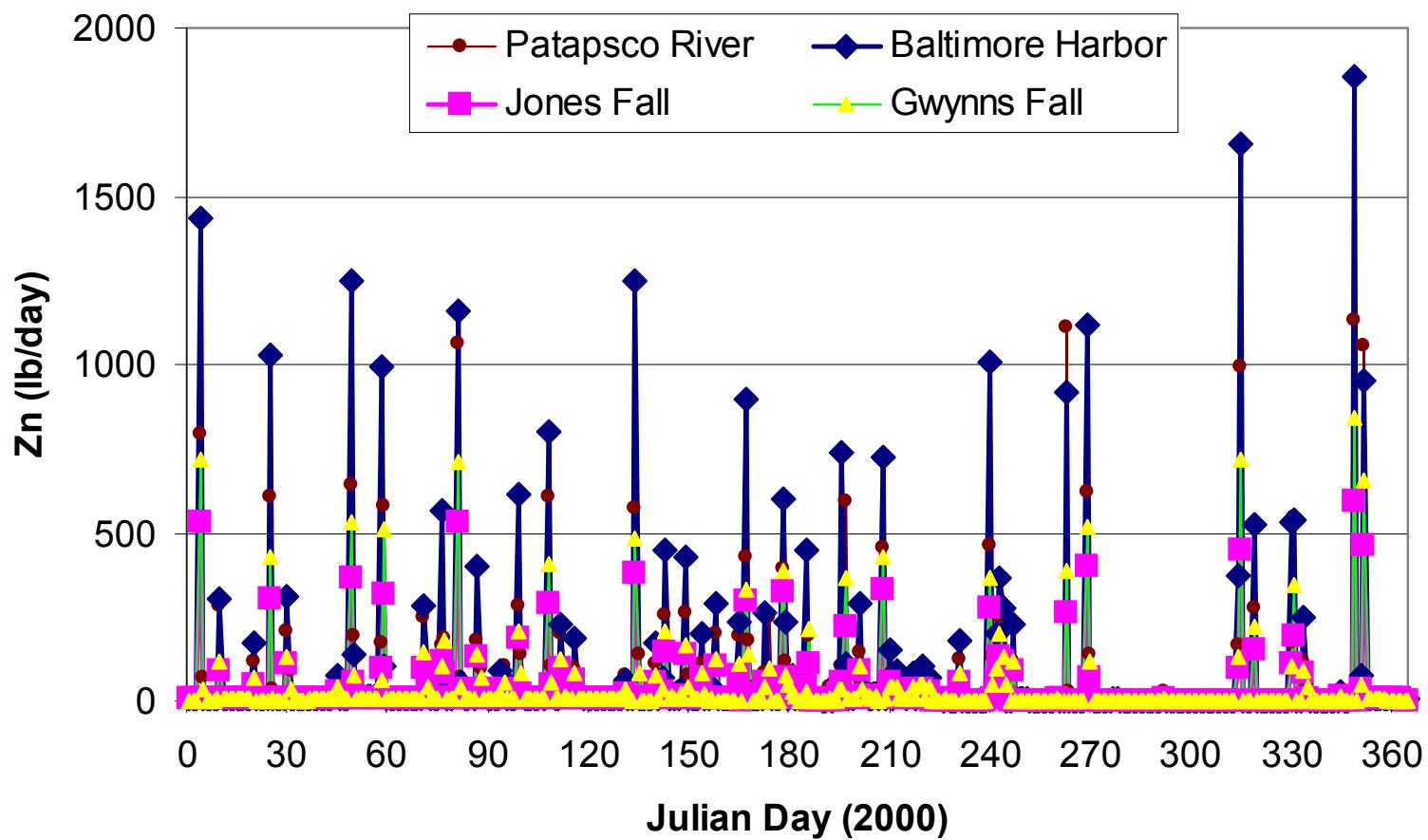


1996 Sediment Mapping Survey (Baker et al., 1997)

## Reference:

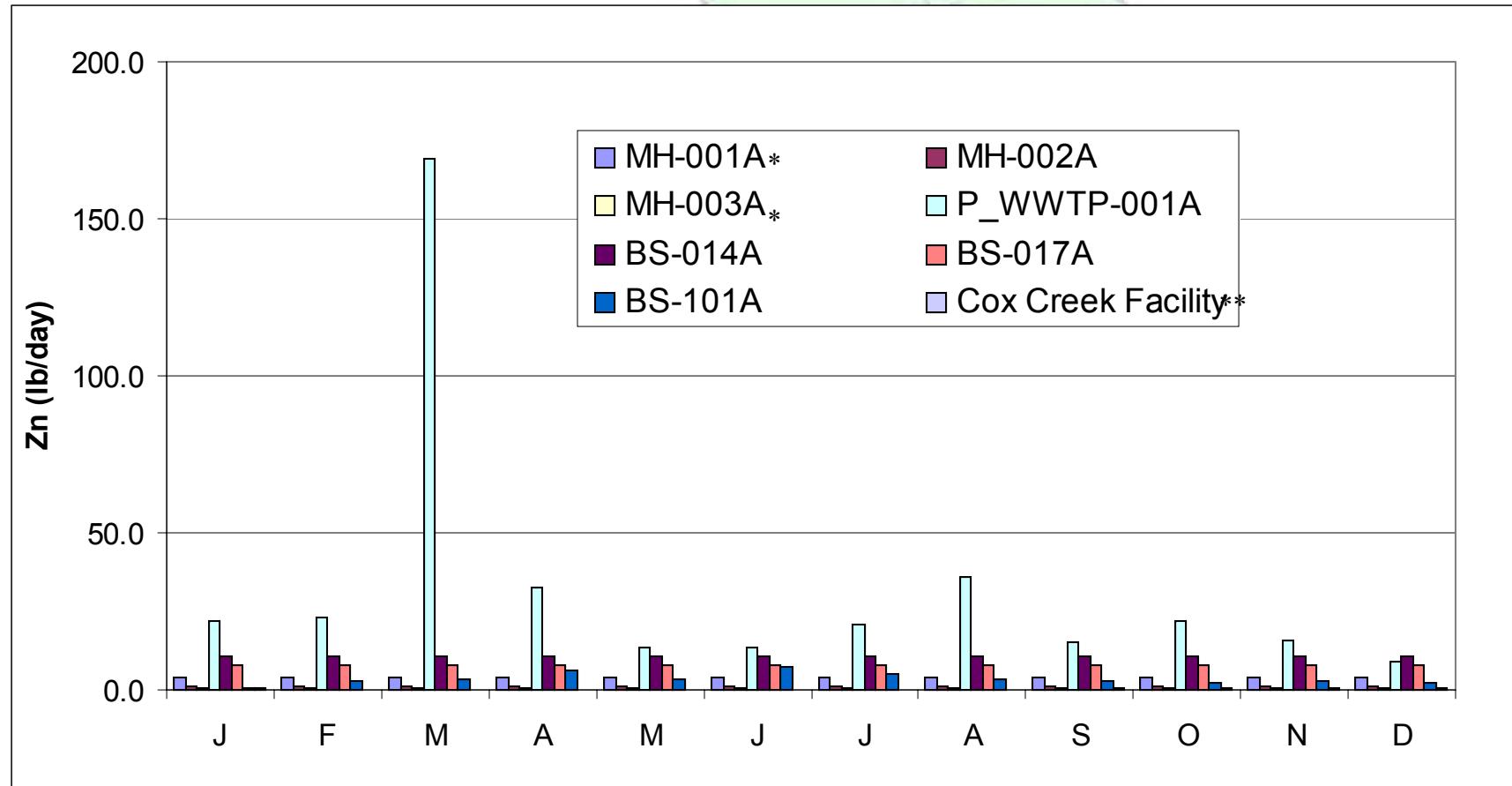
Baker J., R. Mason, J. Cornwell, J. Ashley, J. Halka and J. Hill, 1997, Spatial mapping of sedimentary contaminants in the Baltimore Harbor / Patapsco River/Back River System, Final Report submitted to Maryland Department of the Environment

## Zn non-point source Loadings



Total: 37548.2 kg

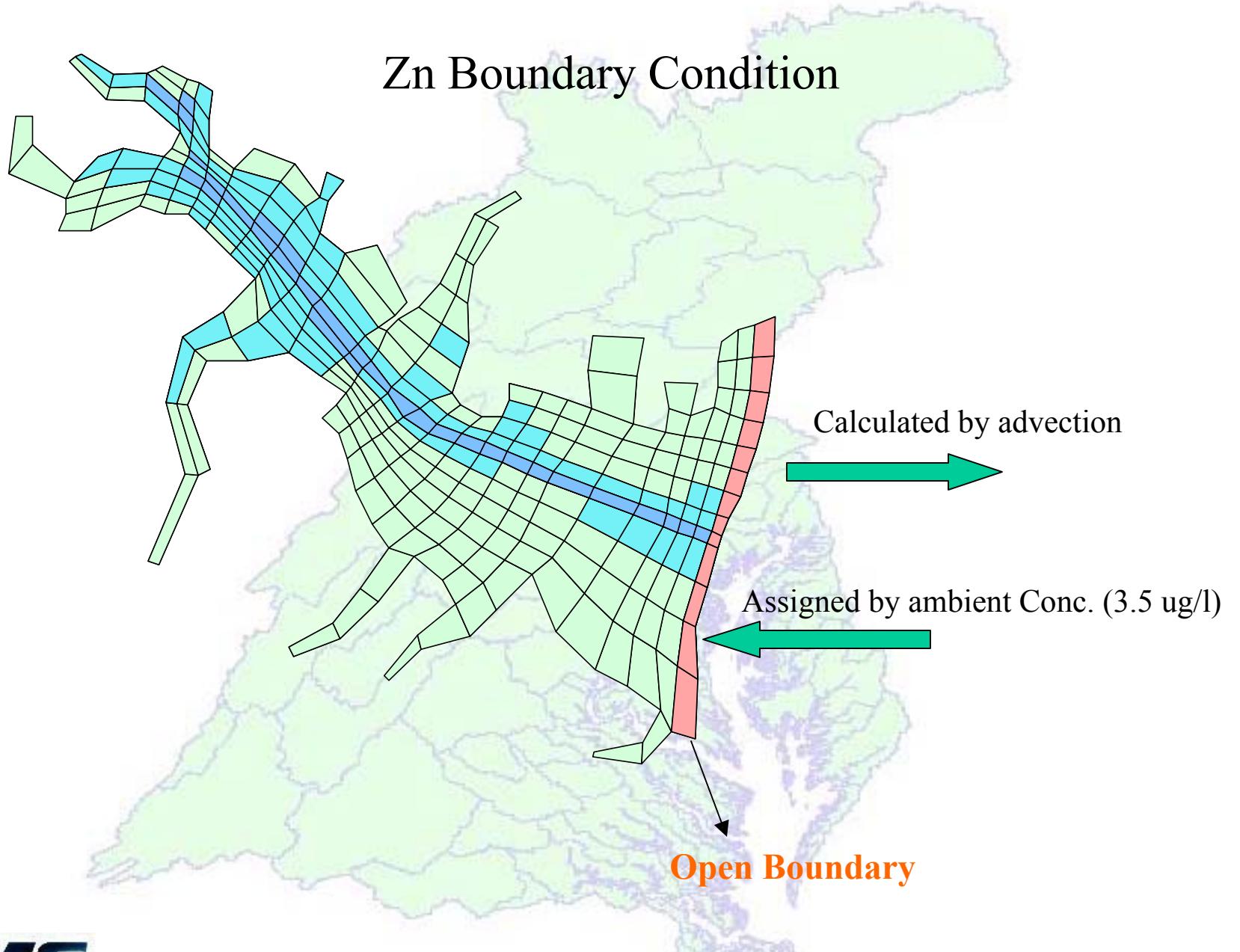
## Zn point source Loadings



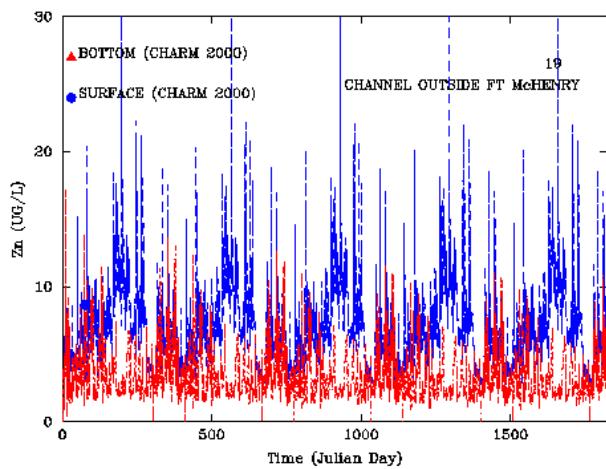
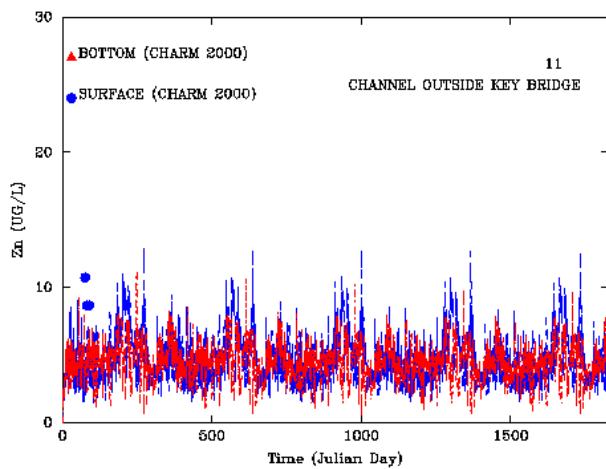
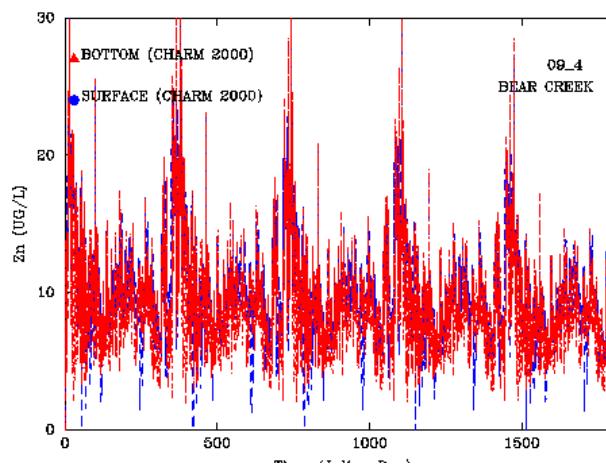
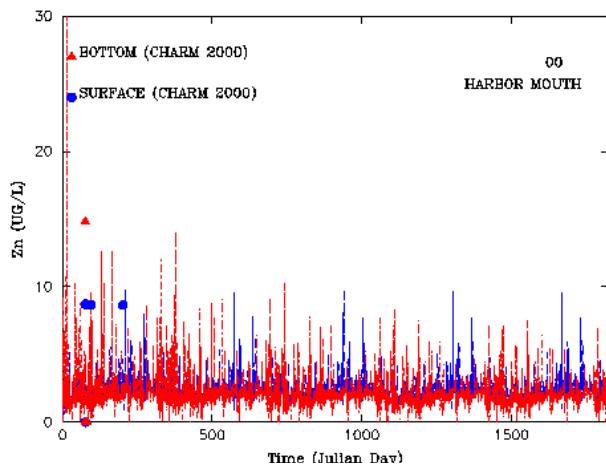
\* Mean values used for Millennium-Hawkins and Beth-Steel 014A

\*\* Included only for scenario model runs

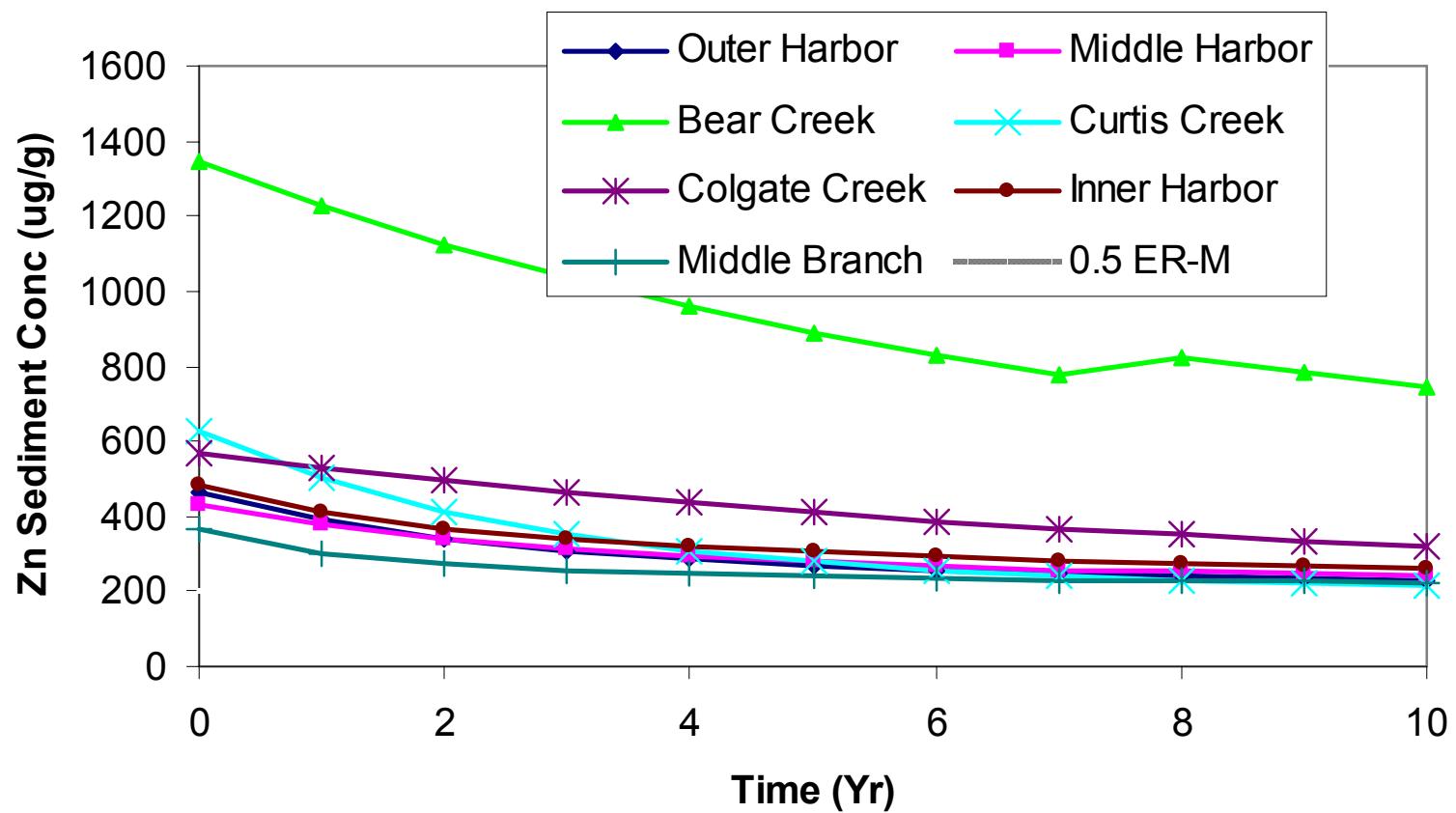
Total: 11672.3 kg



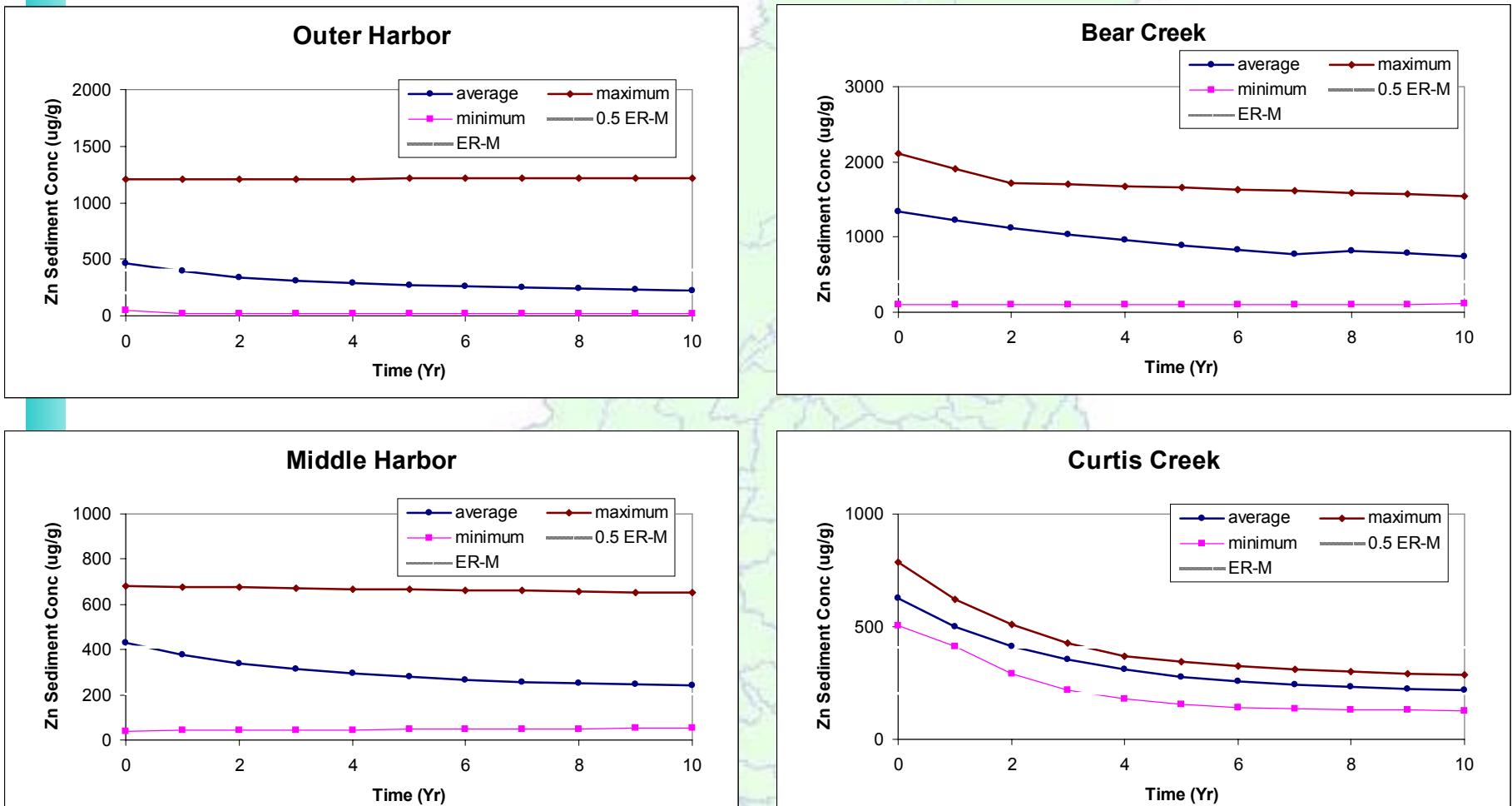
# Zn Water Column Concentration



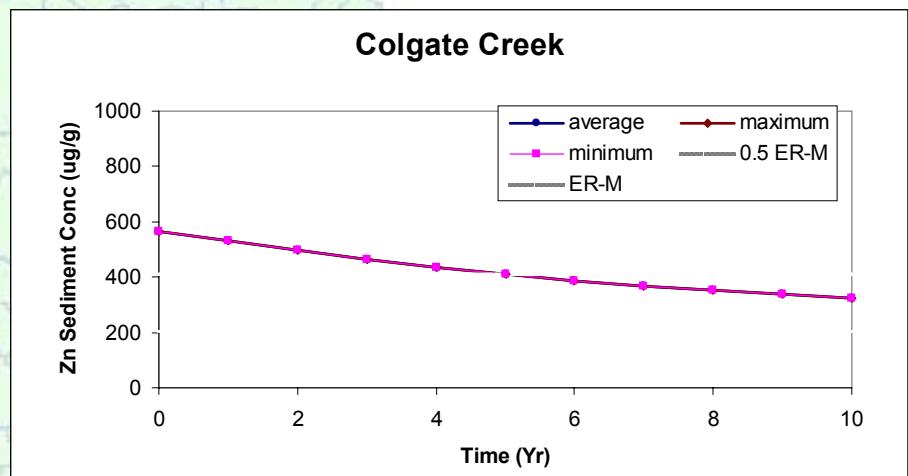
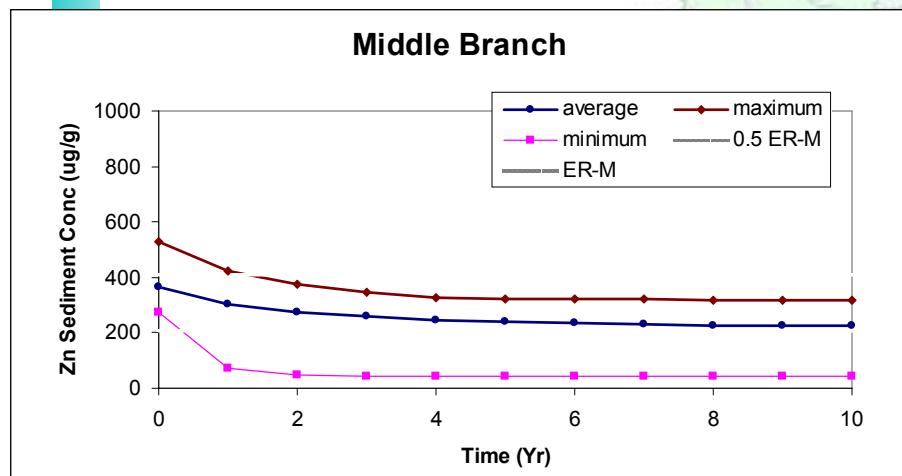
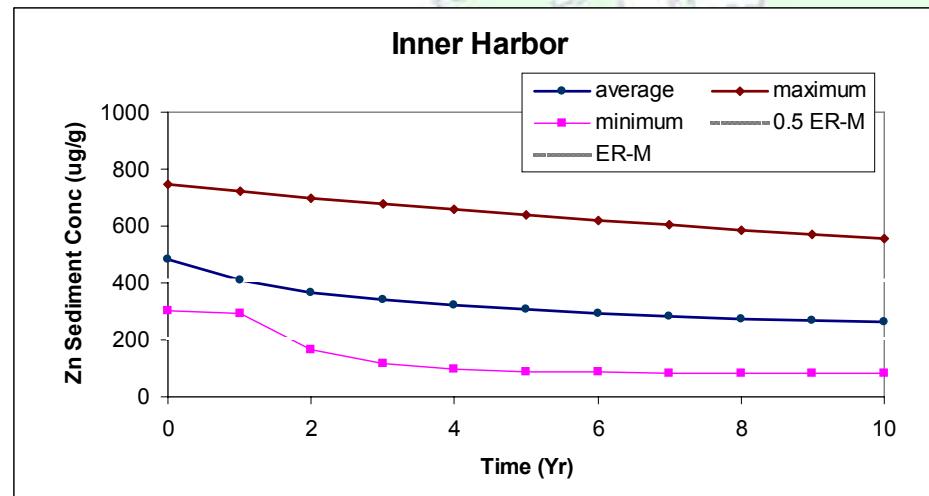
## Zn Sediment Concentration (time series)



# Zn Sediment Concentration (time series)

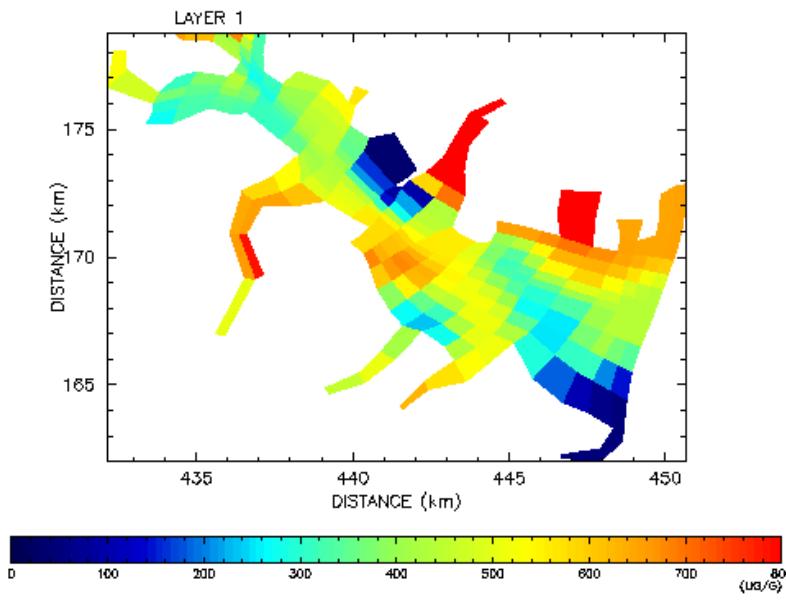


# Zn Sediment Concentration (time series)

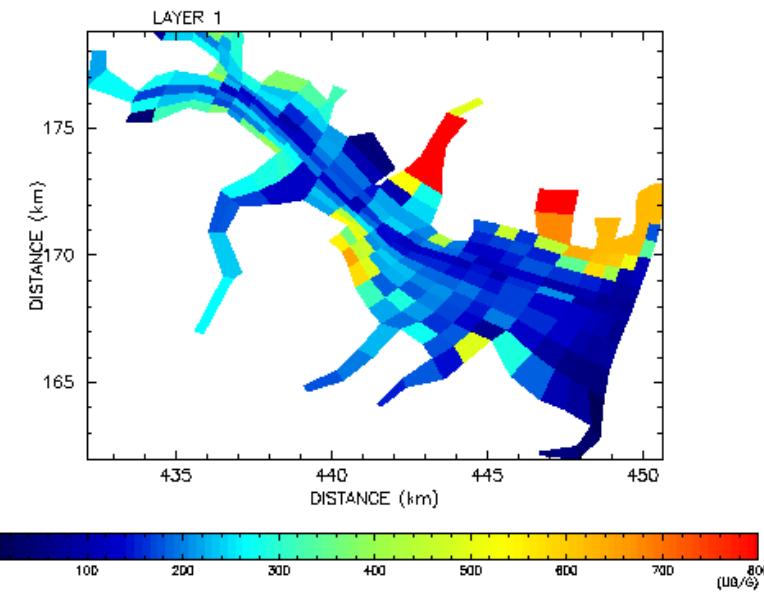


# Zn Sediment Concentration (spatial distribution)

Initial Condition



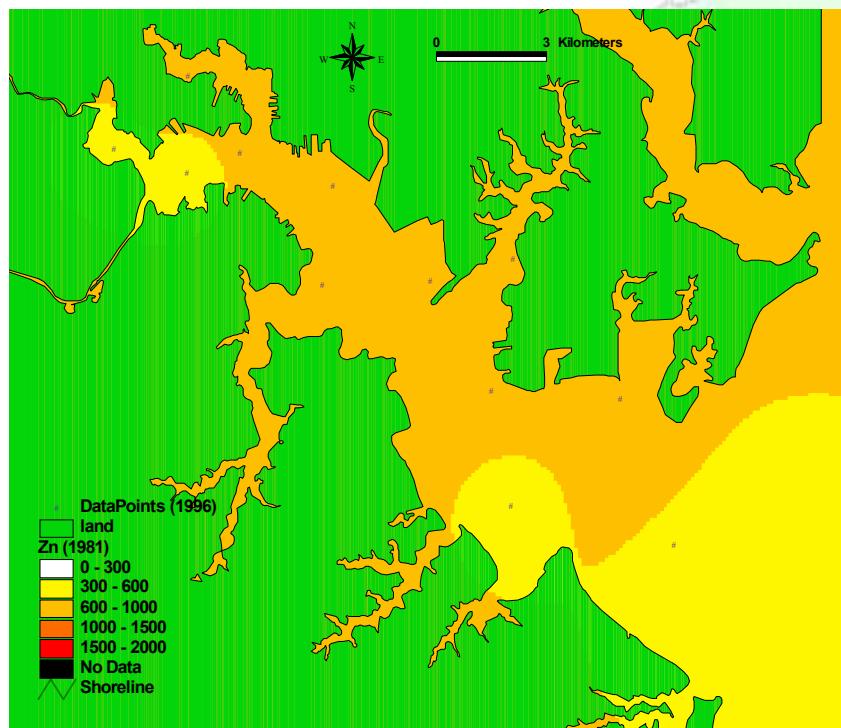
After 10 Year



2-Jun-2003 11:32

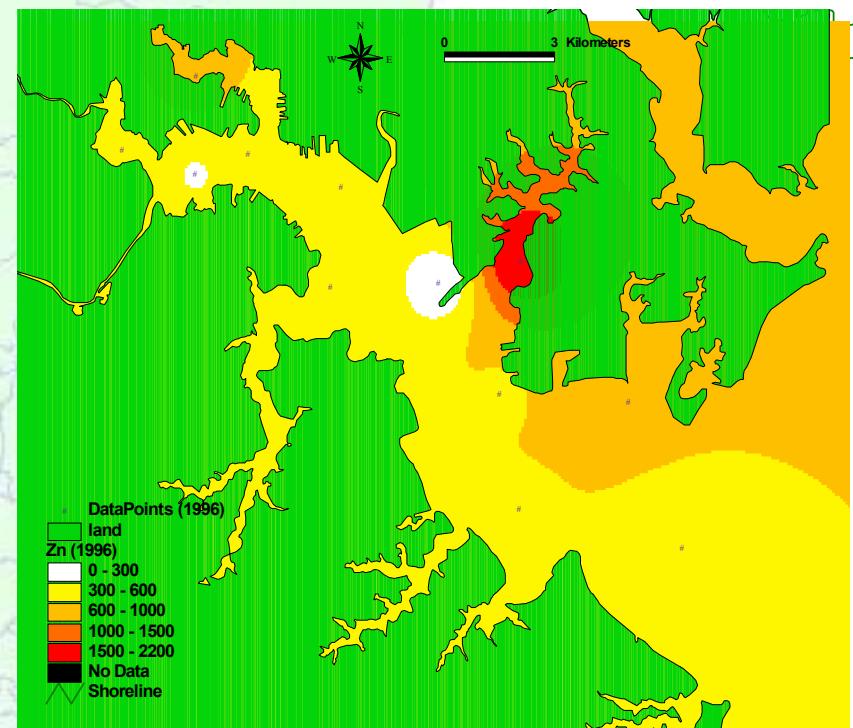
3-Jun-2003 11:32

Zn in 1981



(data from Sinex and Helz, 1982)

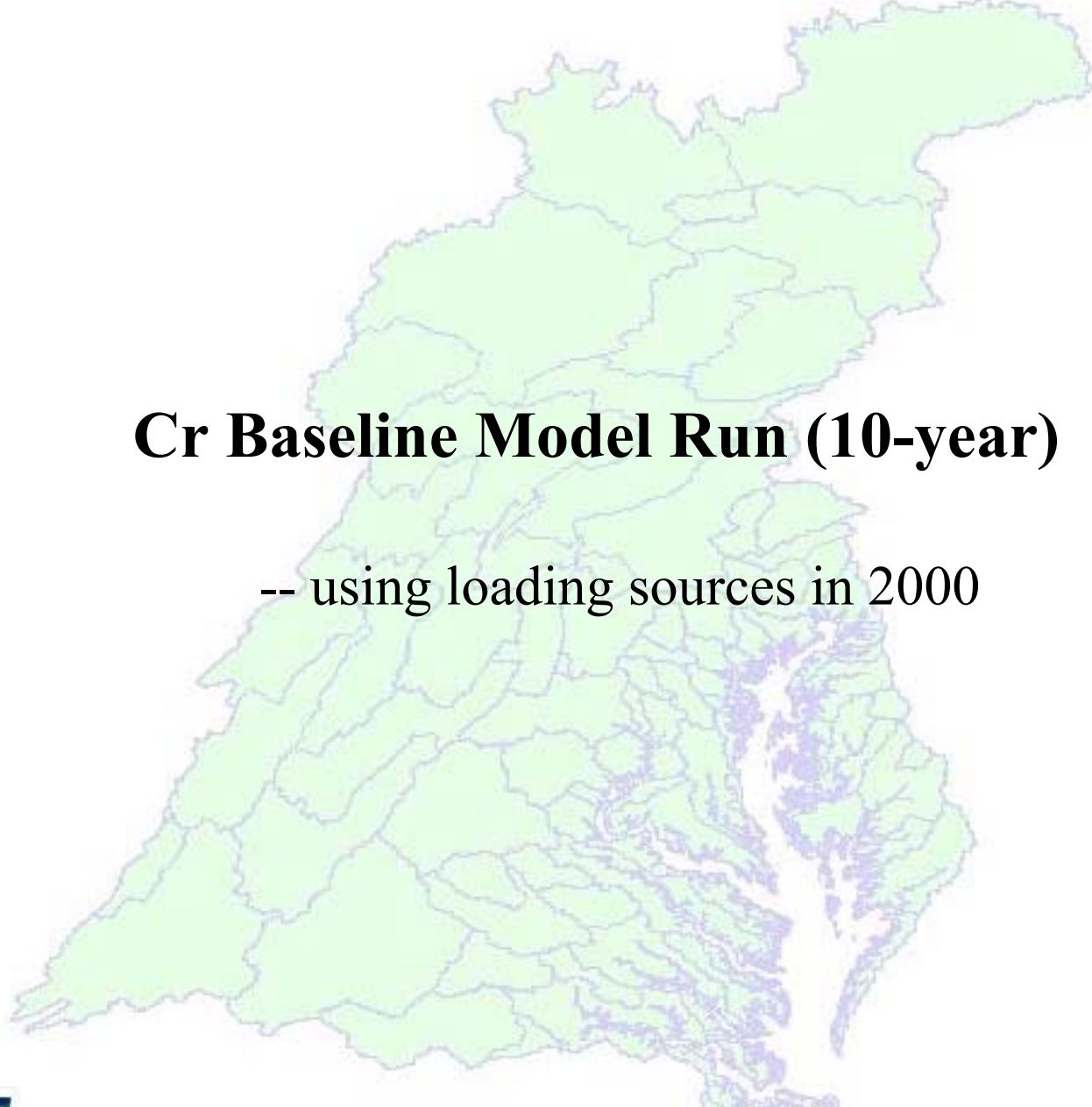
Zn in 1996



(data from Baker et al., 1997)

## Zn Sediment Concentration Changes in Baseline Model Run

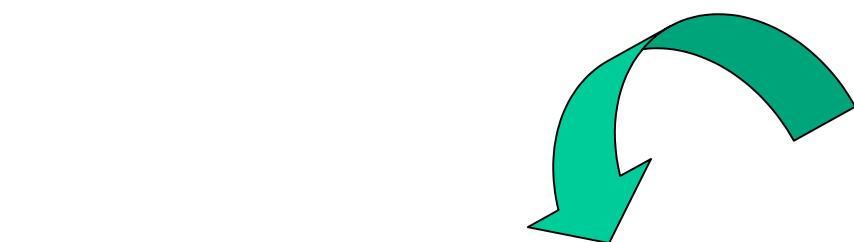
	Outer Harbor	Middle Harbor	Bear Creek	Curtis Creek	Colgate Creek	Inner Harbor	Middle Branch
Average	-238.5 (-51%)	-191.1 (-44%)	-600.2 (-45%)	-410.3 (-65%)	-244.0 (-43%)	-223.3 (-46%)	-141.2 (-39%)
Maximum	18.0 (1%)	-30.9 (-5%)	-569.0 (-27%)	-503.2 (-64%)	-244.0 (-43%)	-187.6 (-25%)	-212.3 (-40%)
Minimum	-32.6 (-68%)	12.6 (32%)	10.7 (11%)	-379.0 (-75%)	-244.0 (-43%)	-218.4 (-72%)	-231.3 (84%)



## **Cr Baseline Model Run (10-year)**

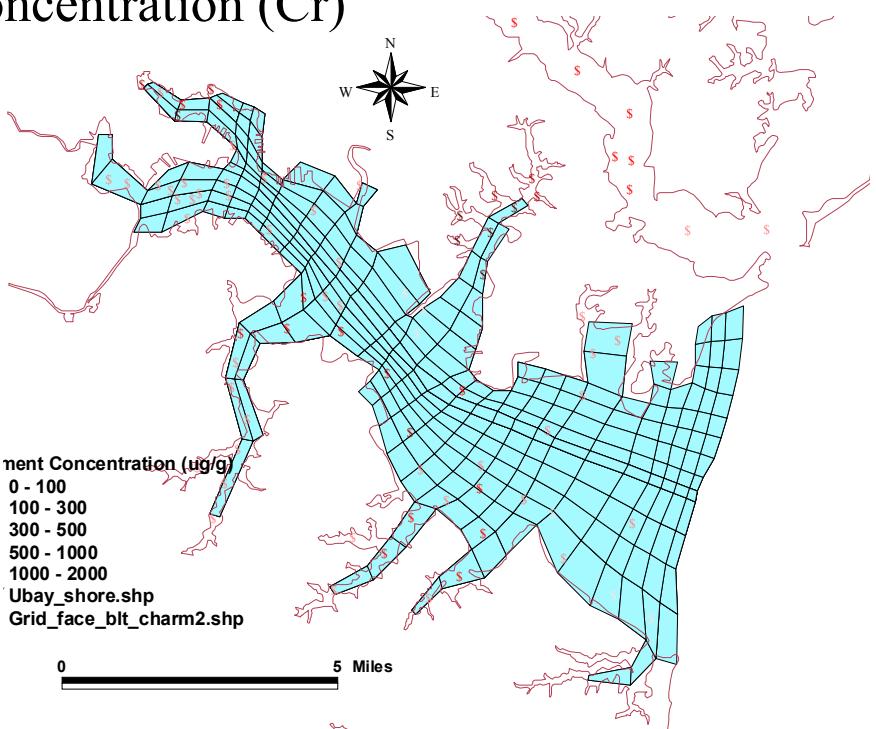
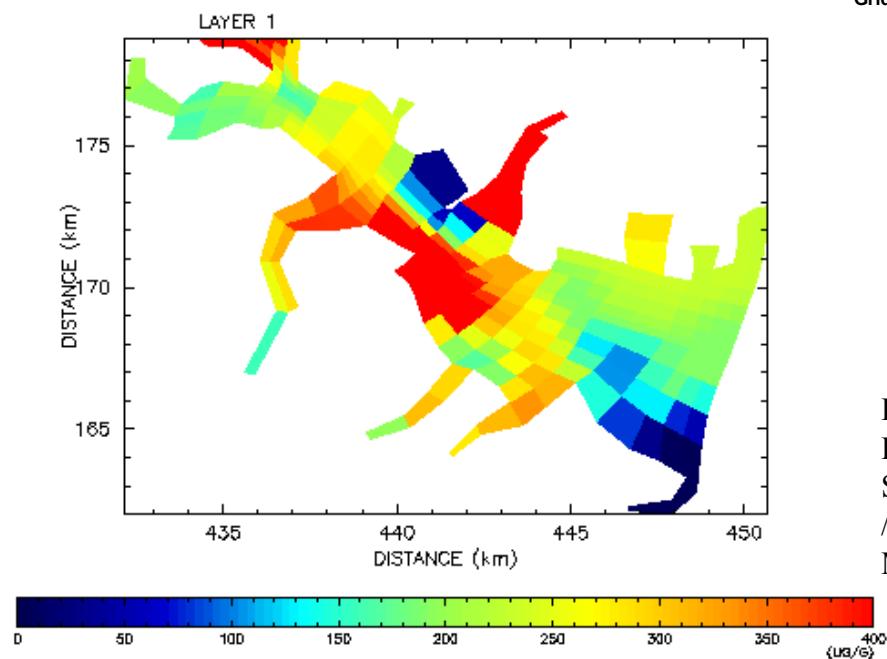
-- using loading sources in 2000

# Initial Sediment Concentration (Cr)

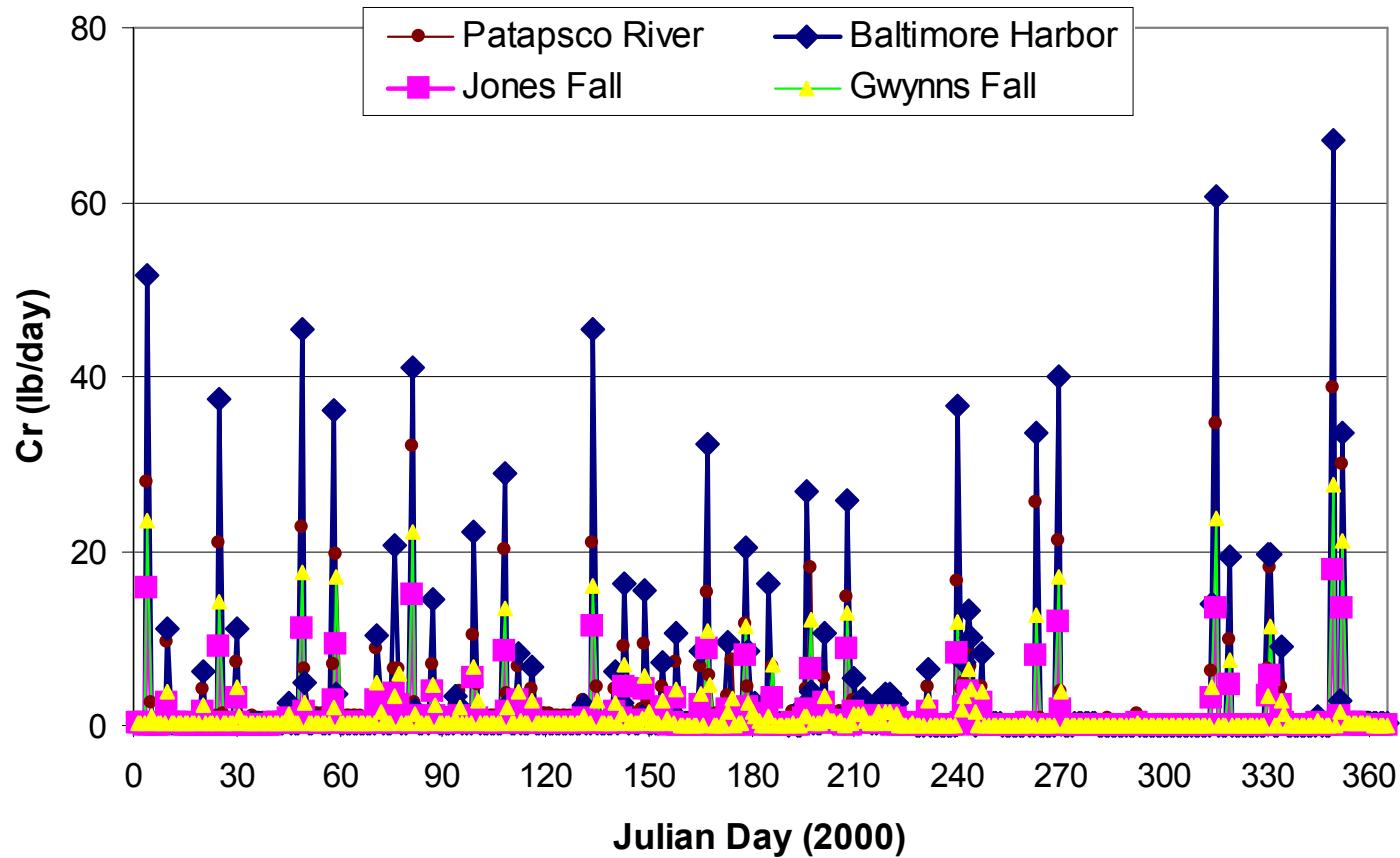


Model Initial Condition

DAY 0.0

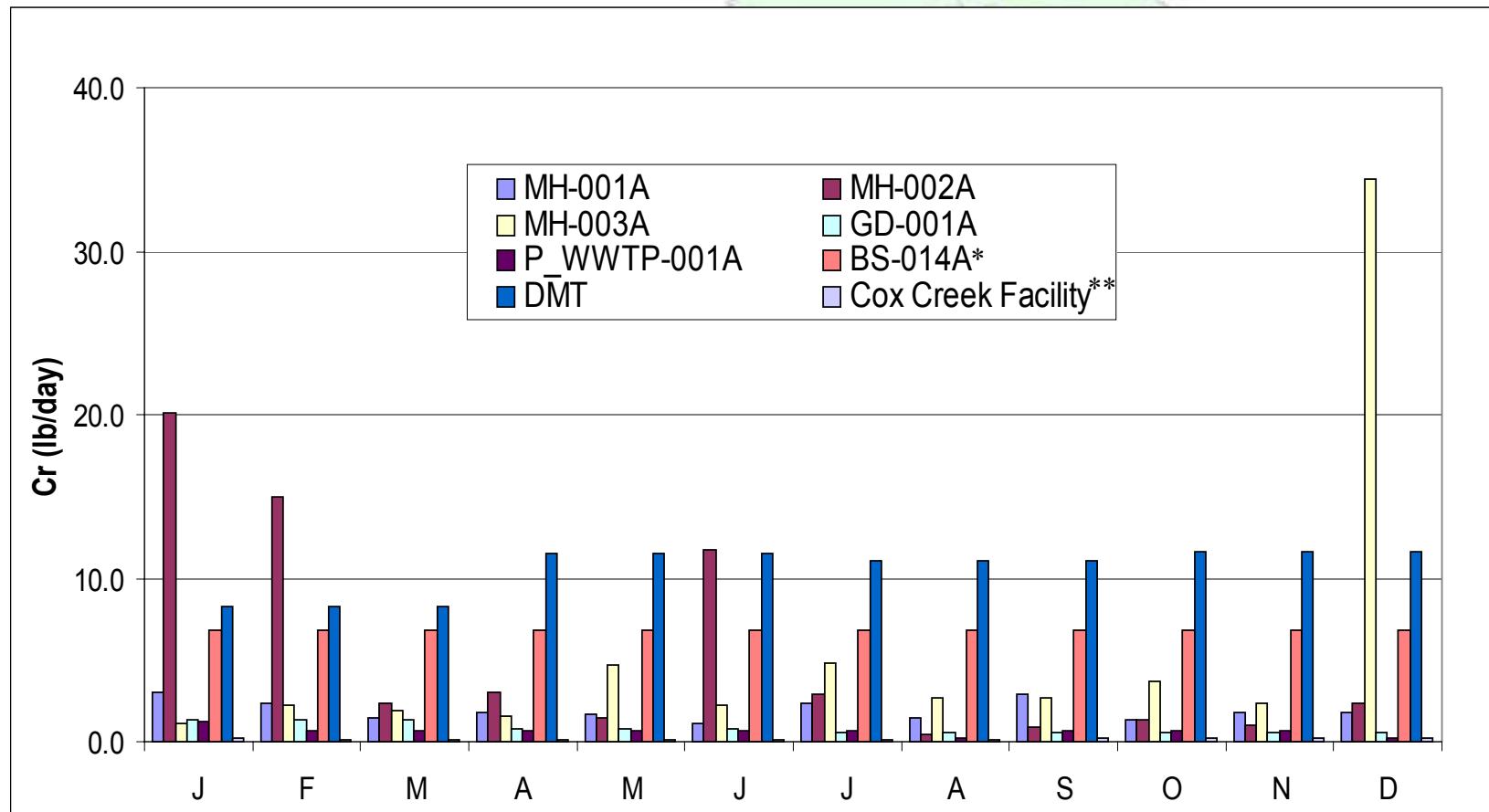


## Cr non-point source Loadings



Total: 1305.7 kg

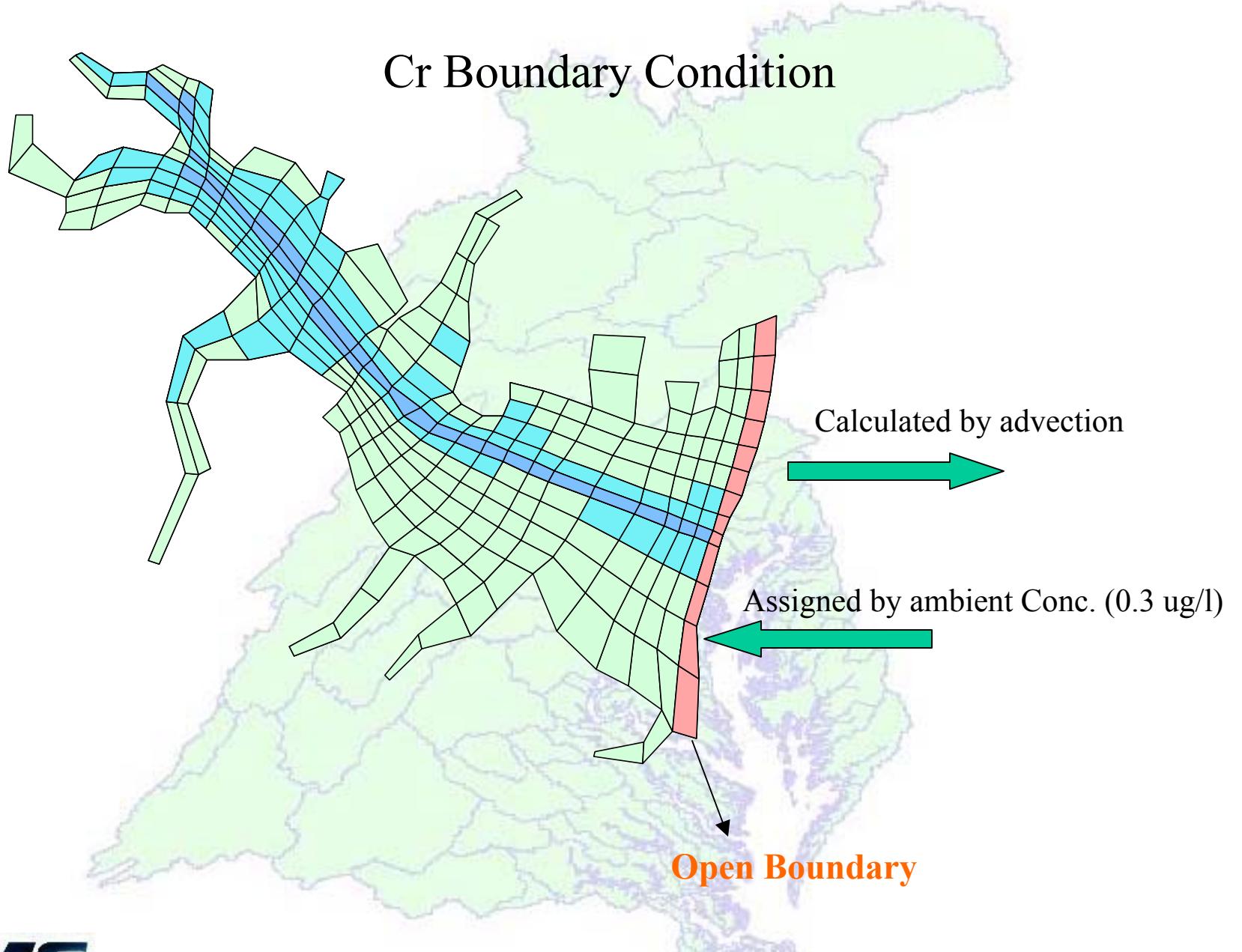
## Cr point source Loadings



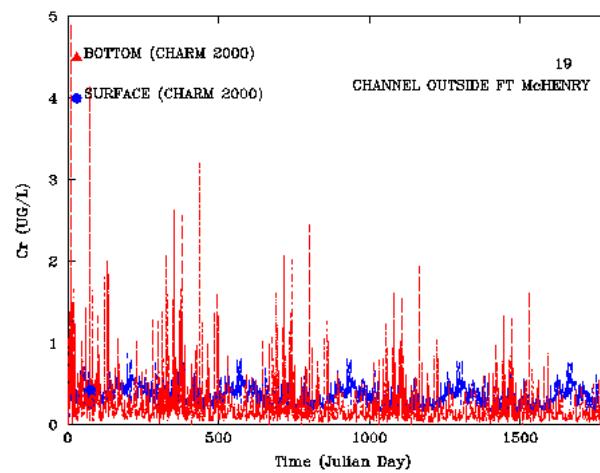
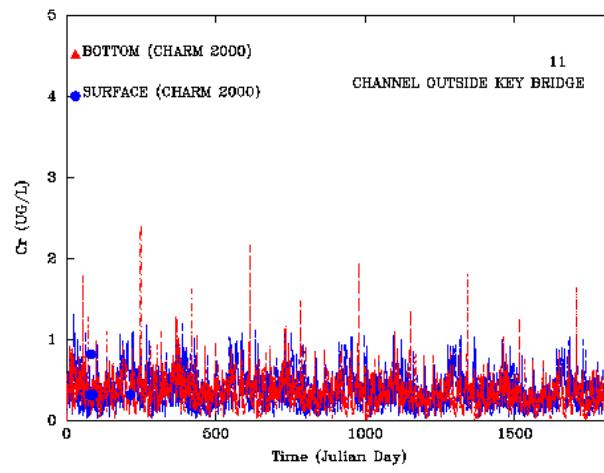
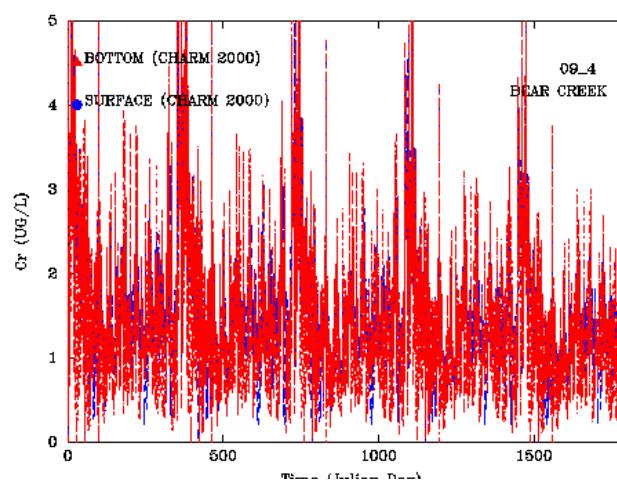
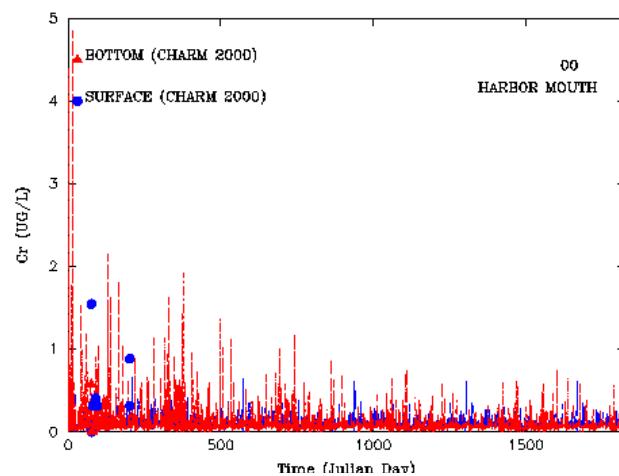
\* Mean value used for Bethlehem Steel

\*\* Included only for scenario model runs

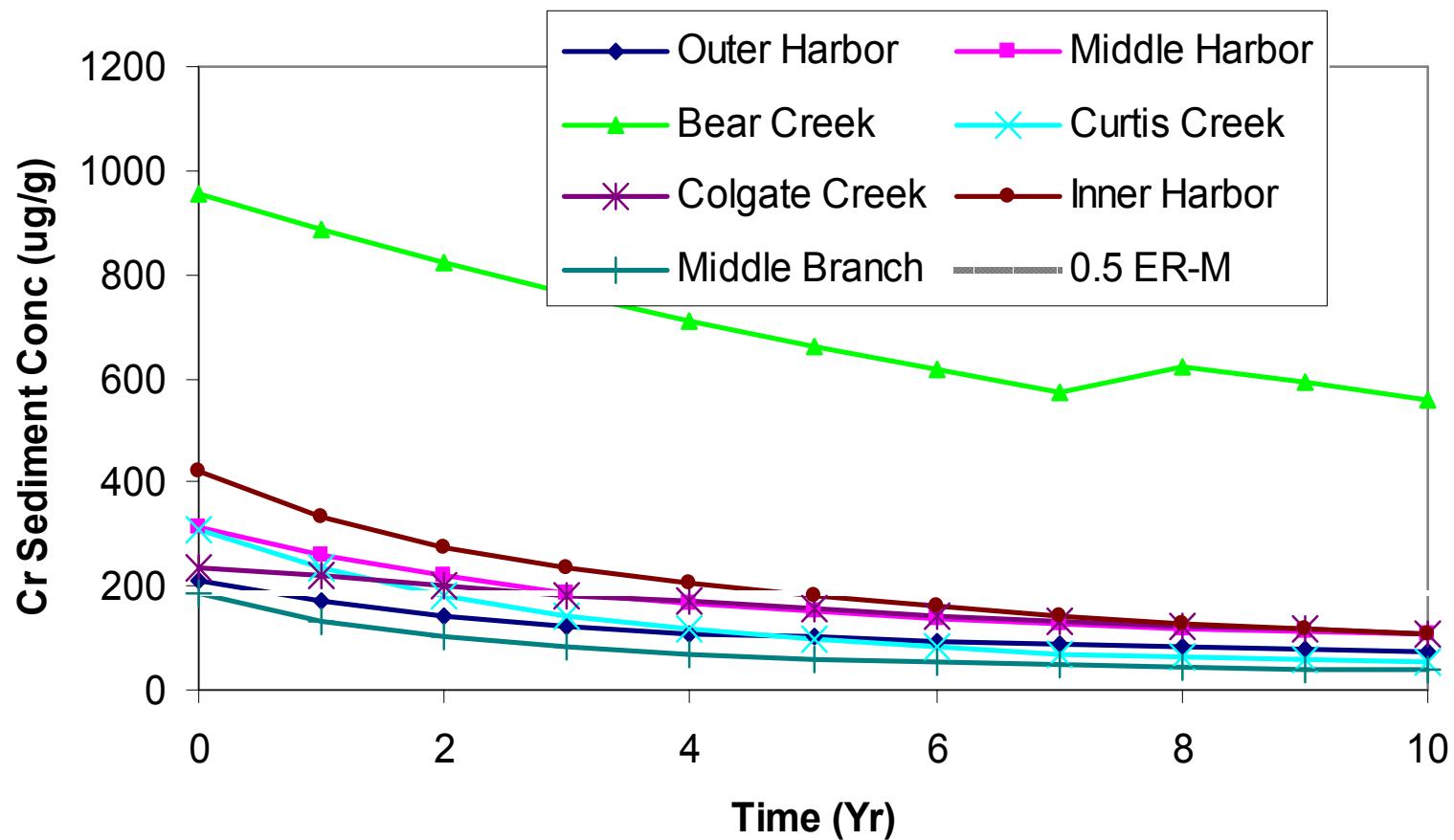
Total: 4532.9 kg



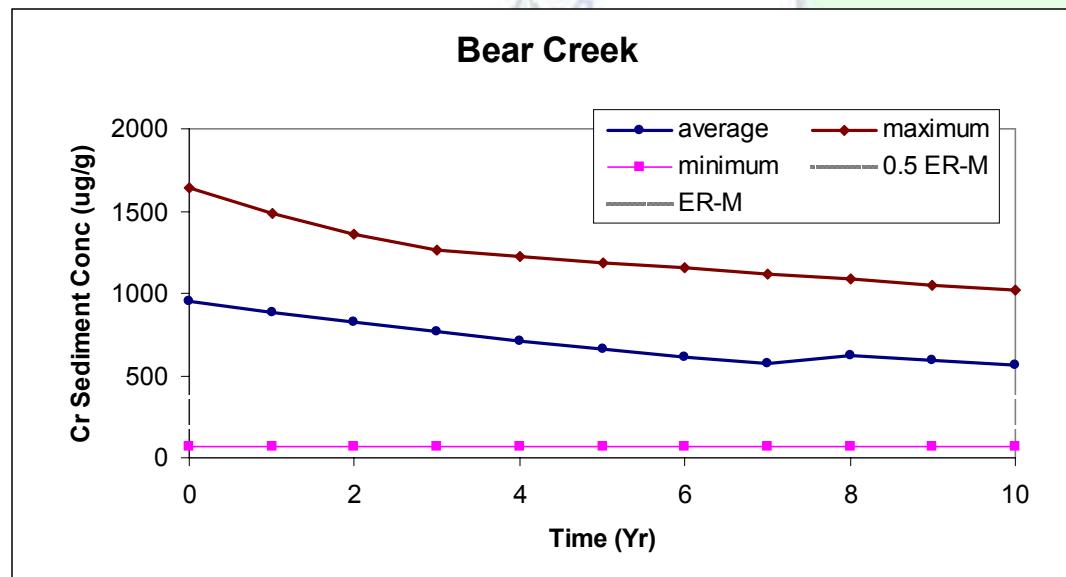
# Cr Water Column Concentration



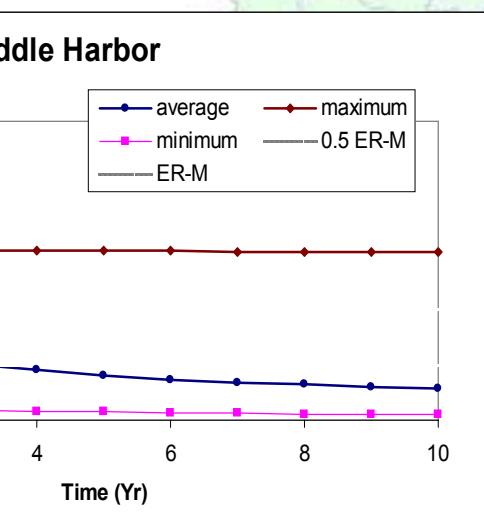
## Cr Sediment Concentration (time series)



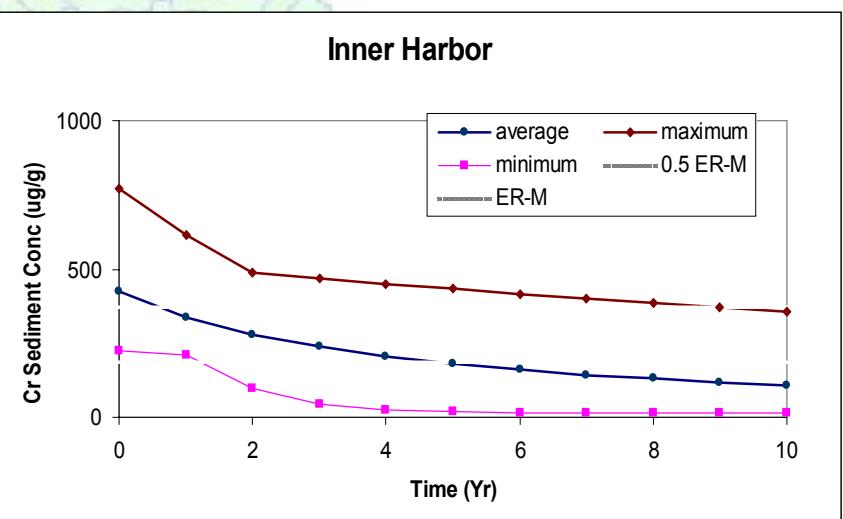
# Cr Sediment Concentration (time series)



**Middle Harbor**



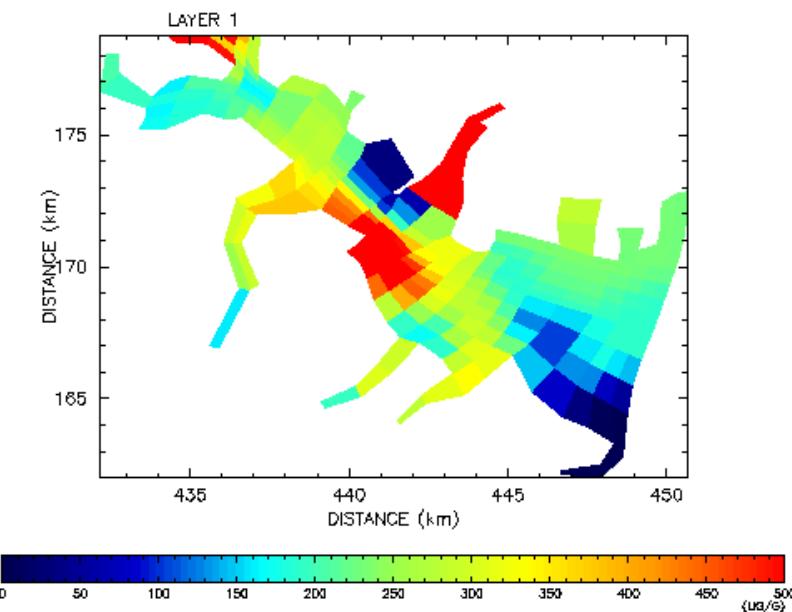
**Inner Harbor**



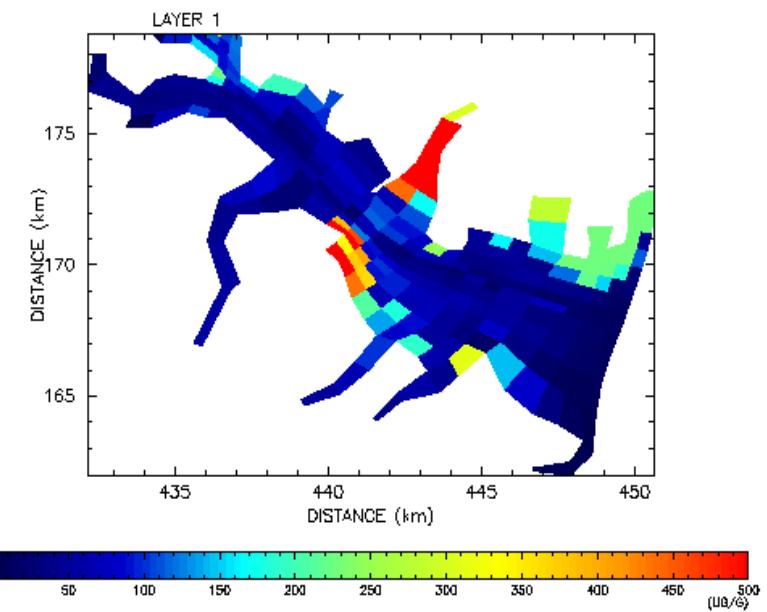
# Cr Sediment Concentration (spatial distribution)



Initial Condition



After 10 Year

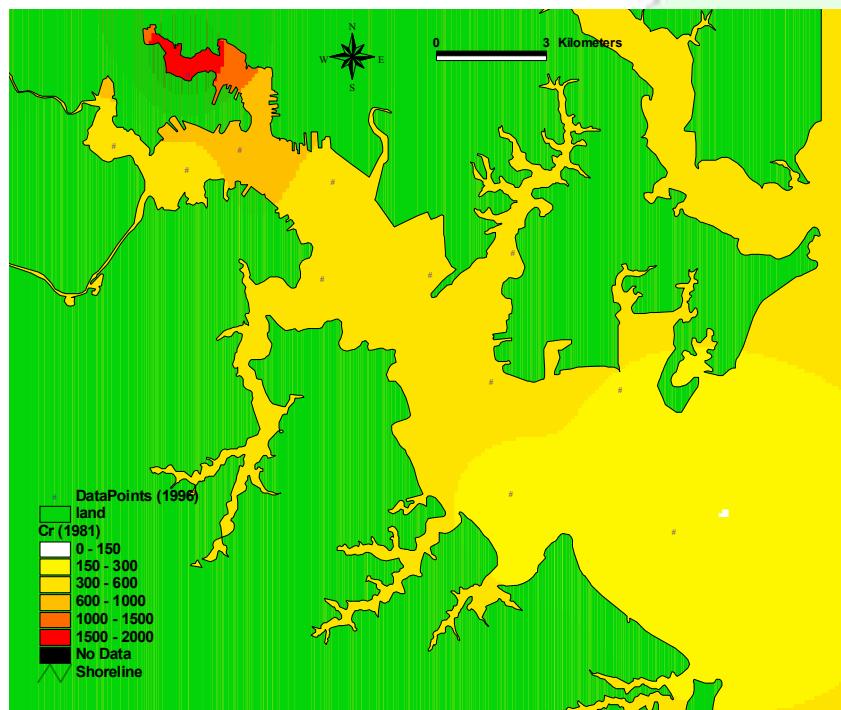


2-Jun-2003 13:38

2-Jun-2003 13:36

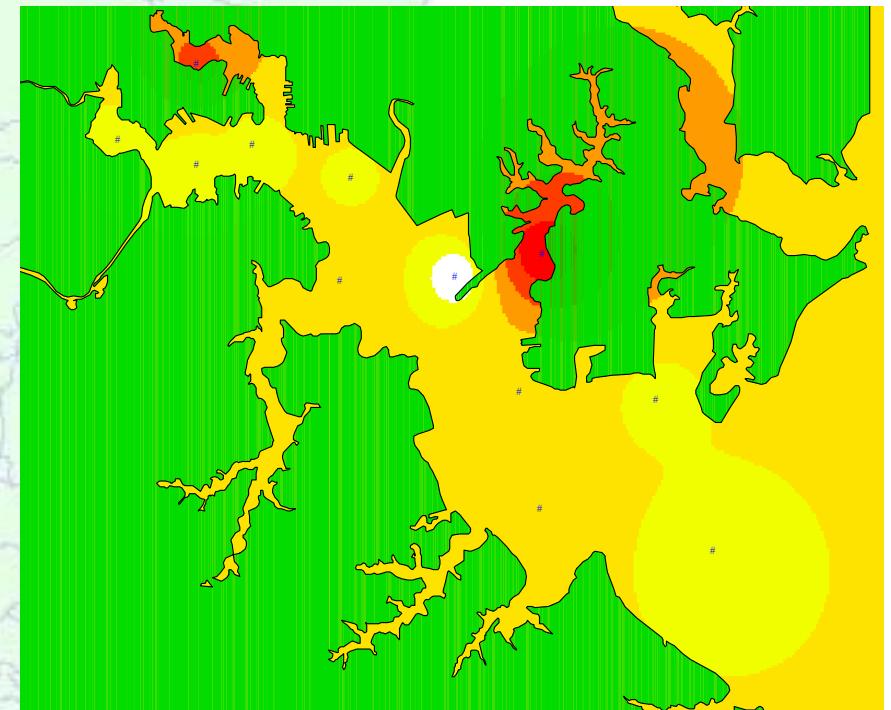


Cr in 1981



(data from Sinex and Helz, 1982)

Cr in 1996



(data from Baker et al., 1997)

## Cr Sediment Concentration Changes in Baseline Model Run

	Outer Harbor	Middle Harbor	Bear Creek	Curtis Creek	Colgate Creek	Inner Harbor	Middle Branch
Average	-136.7 (-64%)	-205.1 (-66%)	-393.5 (-41%)	-254.3 (-83%)	-128.4 (-54%)	-315.3 (-75%)	-147.8 (-80%)
Maximum	-23.6 (-7%)	-8.2 (-1%)	-618.0 (-38%)	-293.9 (-77%)	-128.4 (-54%)	-417.4 (-54%)	-141.1 (-68%)
Minimum	-3.9 (68%)	-13.6 (-40%)	2.1 (3%)	-132.7 (-83%)	-128.4 (-54%)	-214.0 (-95%)	-157.9 (97%)

# Contents

- **Introduction**
- **Toxic Model Calibration**
- **Scenario Model Runs**
- **Sensitivity Test**

# Scenarios for Model Runs:

Source	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Point source	On	Off	Off	On	On
Nonpoint source	On	Off	On	Off	On
Bay source	On	Off	On	On	Off

Baseline Loading

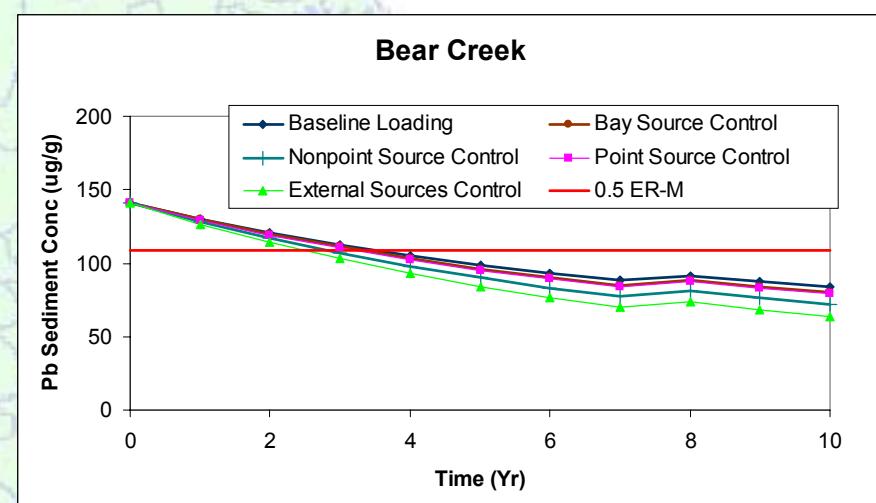
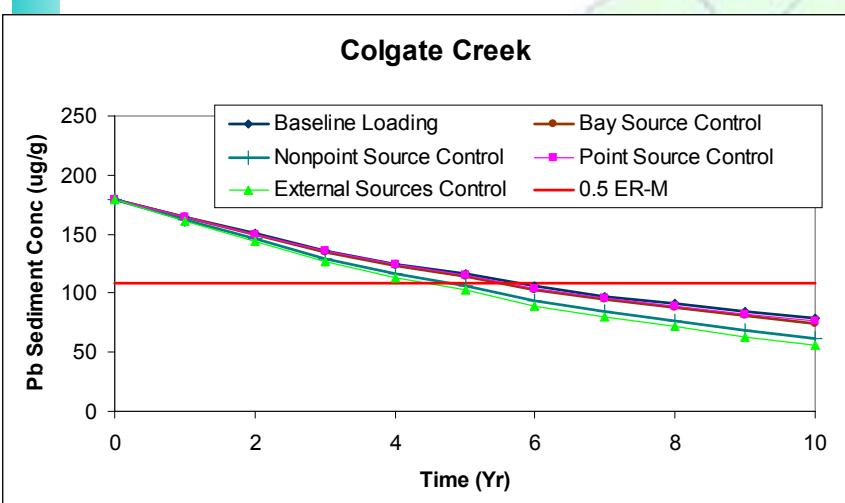
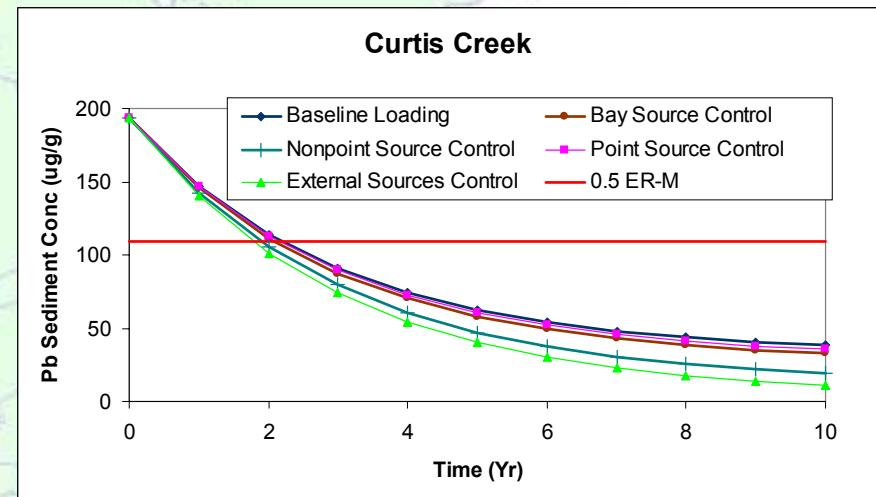
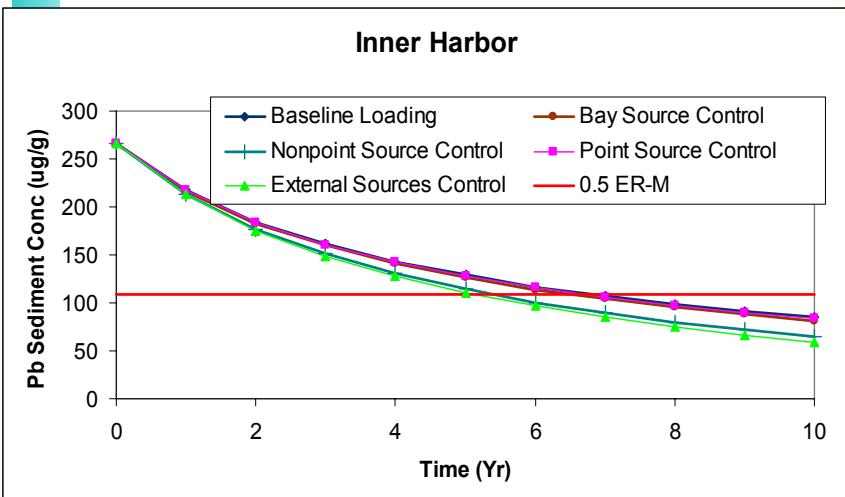
Point Source Control

Bay Source Control

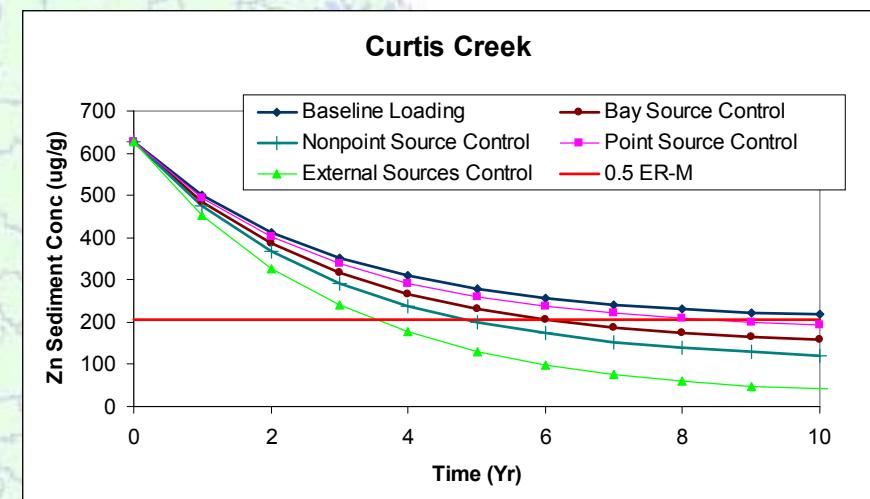
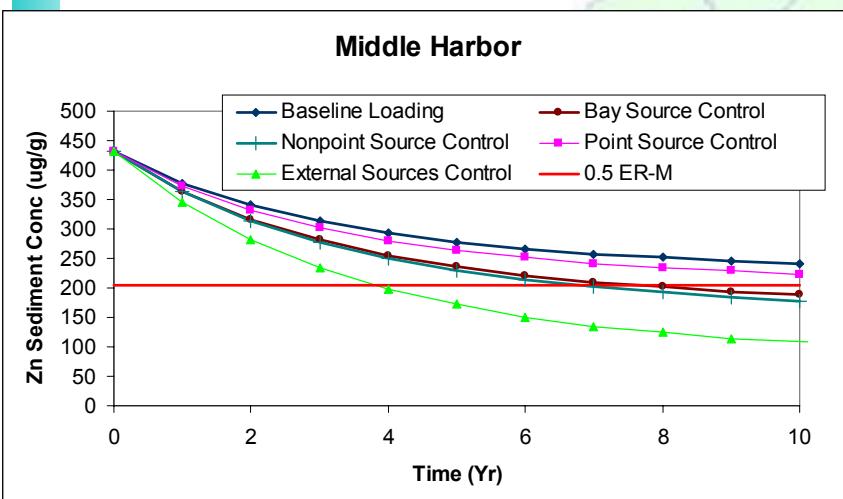
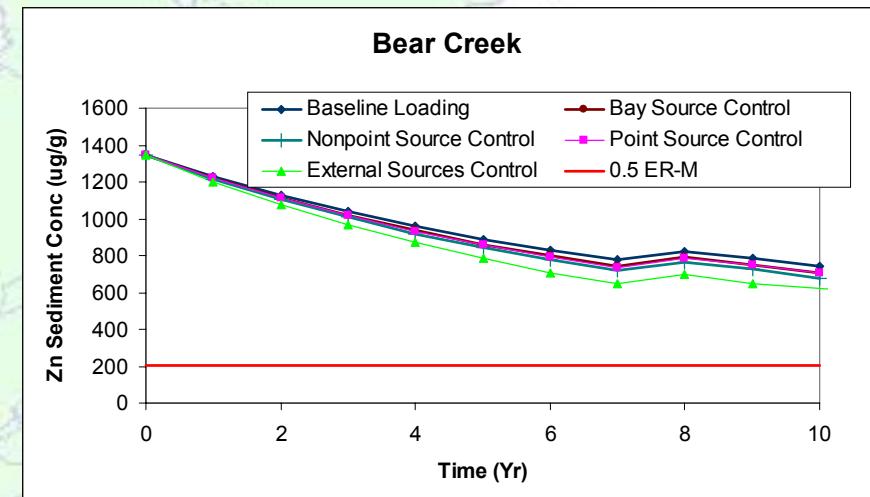
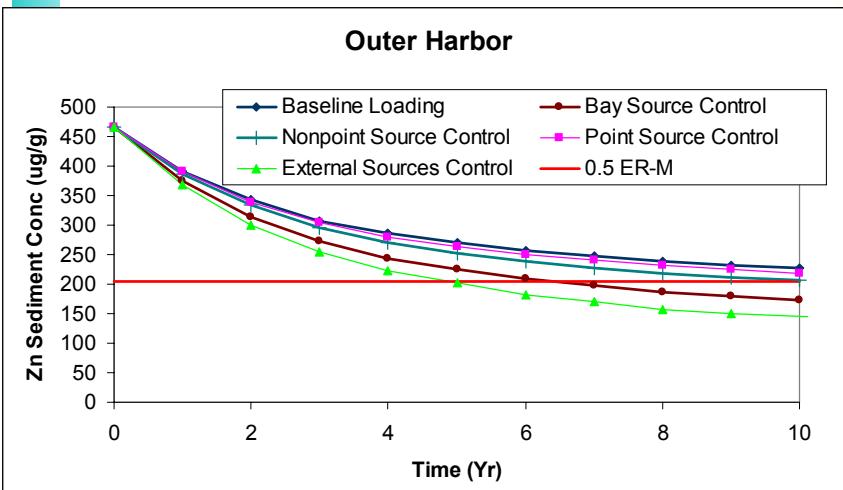
External Sources Control

Nonpoint Source Control

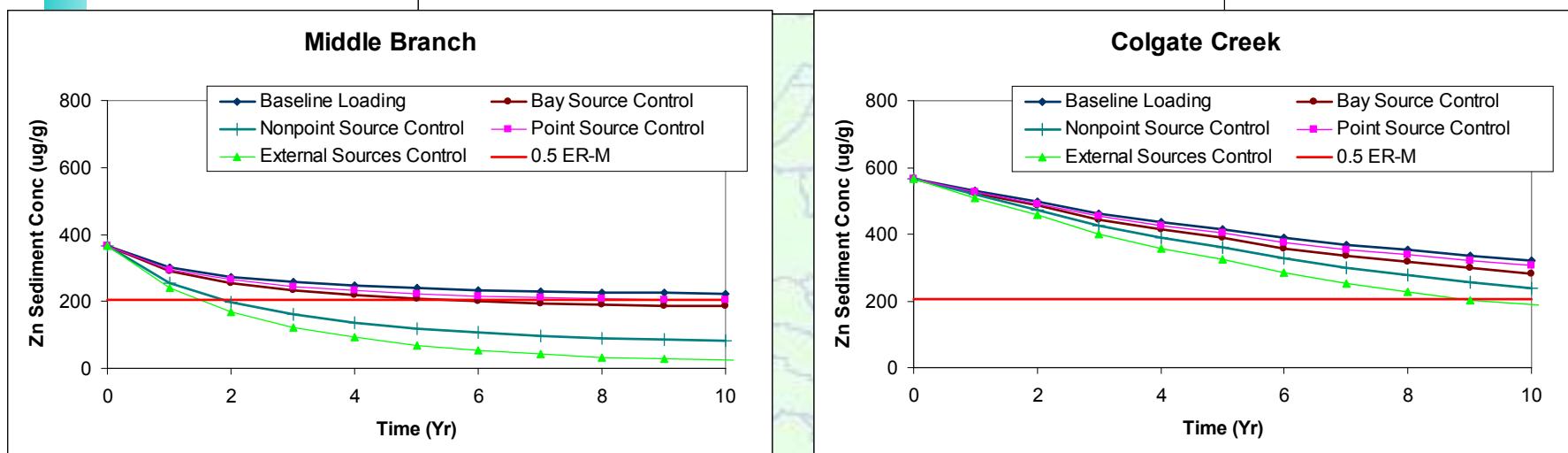
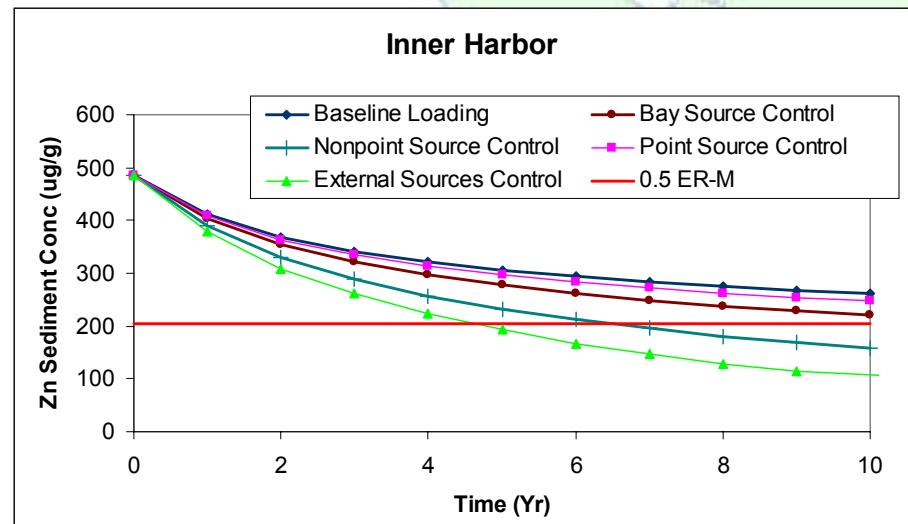
# Pb sediment concentration



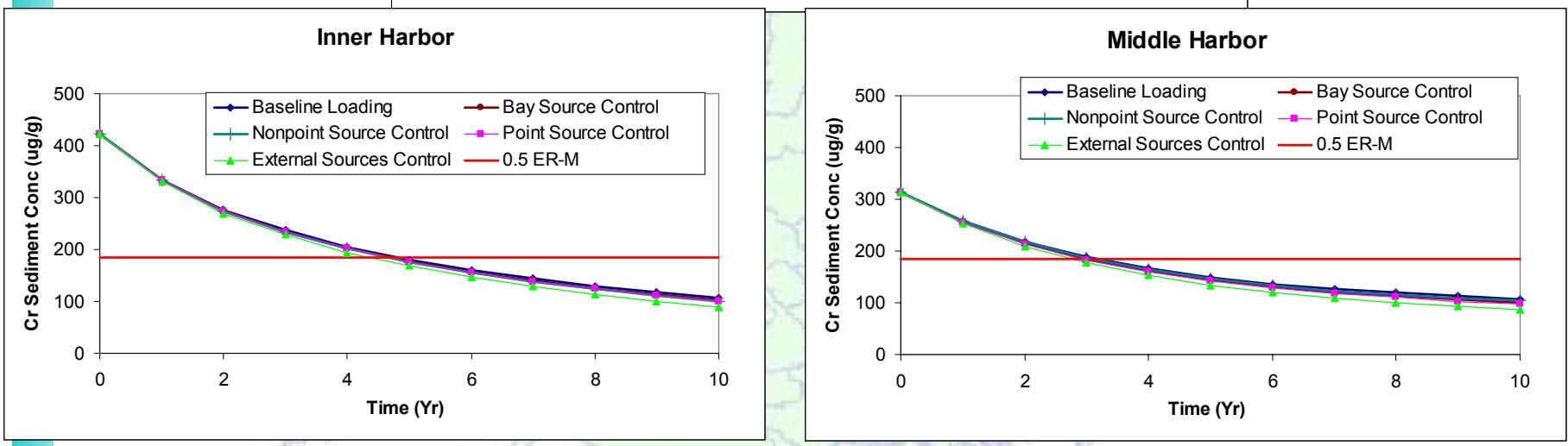
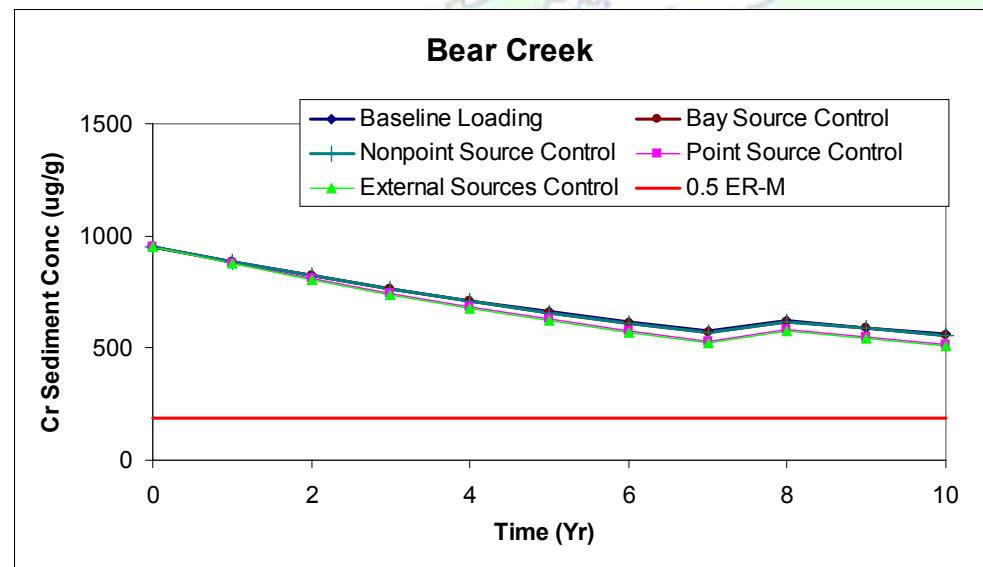
# Zn sediment concentration



# Zn sediment concentration



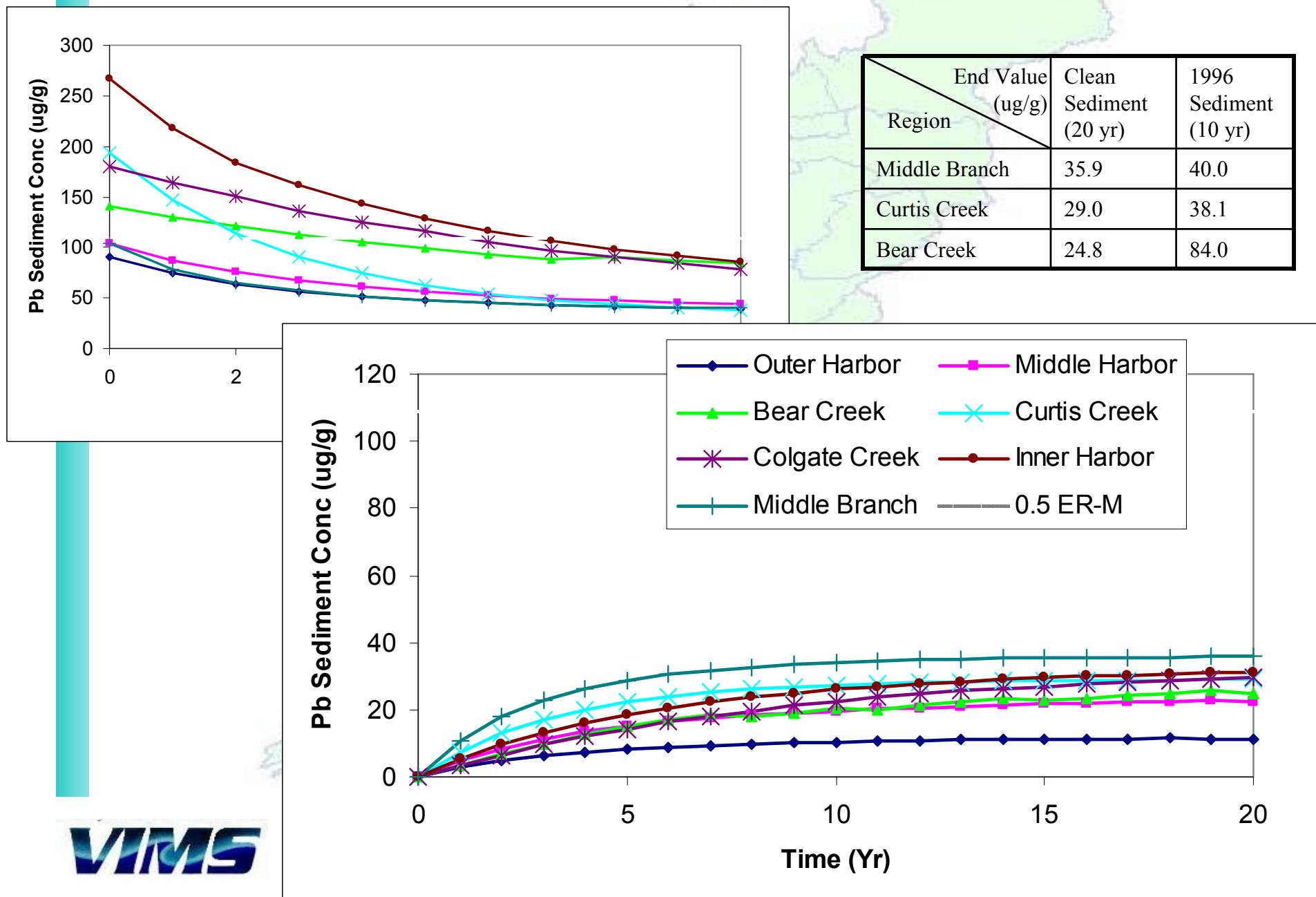
# Cr sediment concentration



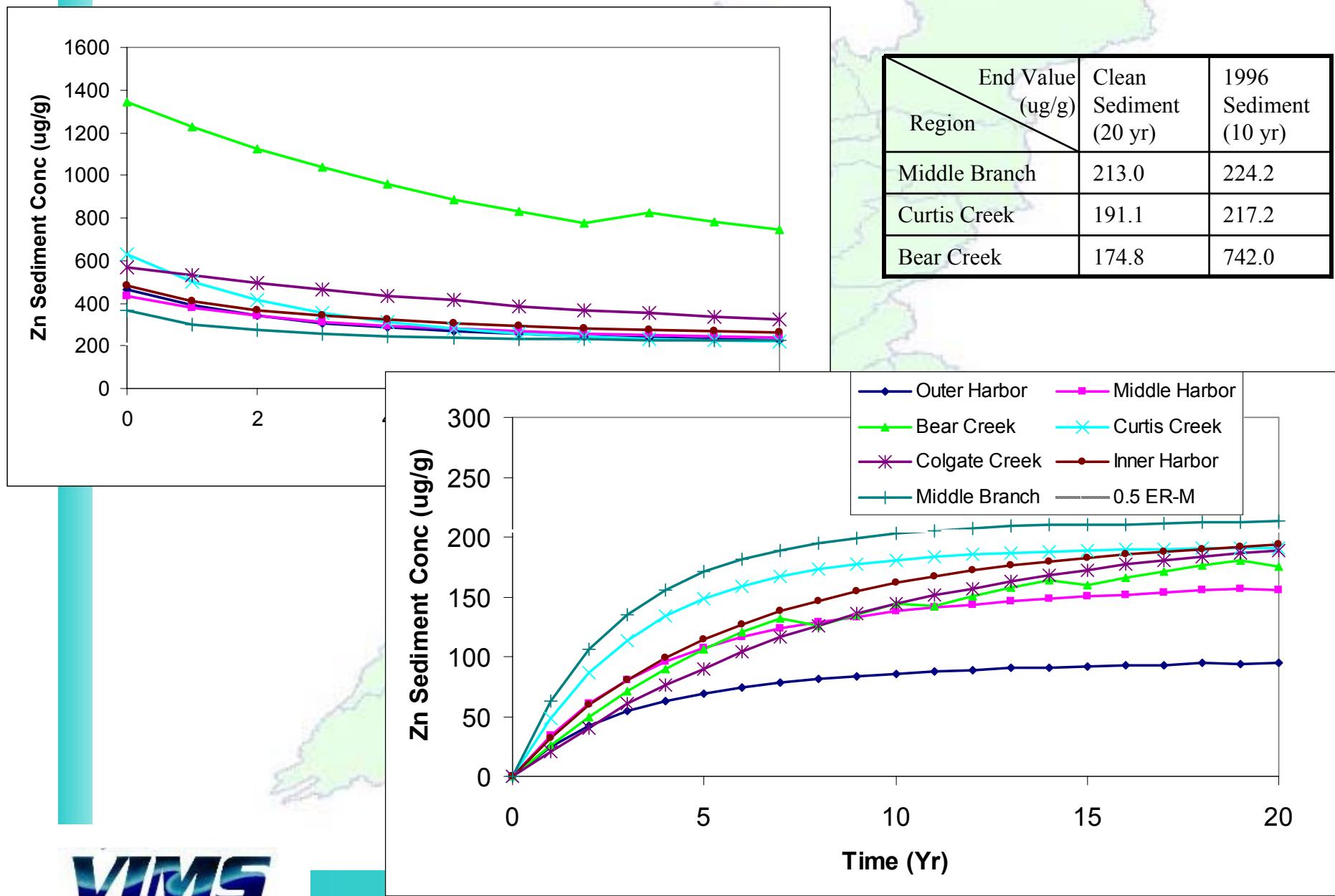
# Contents

- **Introduction**
- **Toxic Model Calibration**
- **Scenario Model Runs**
- **Sensitivity Test**
  - a) Clean sediment
  - b) Partition coefficient

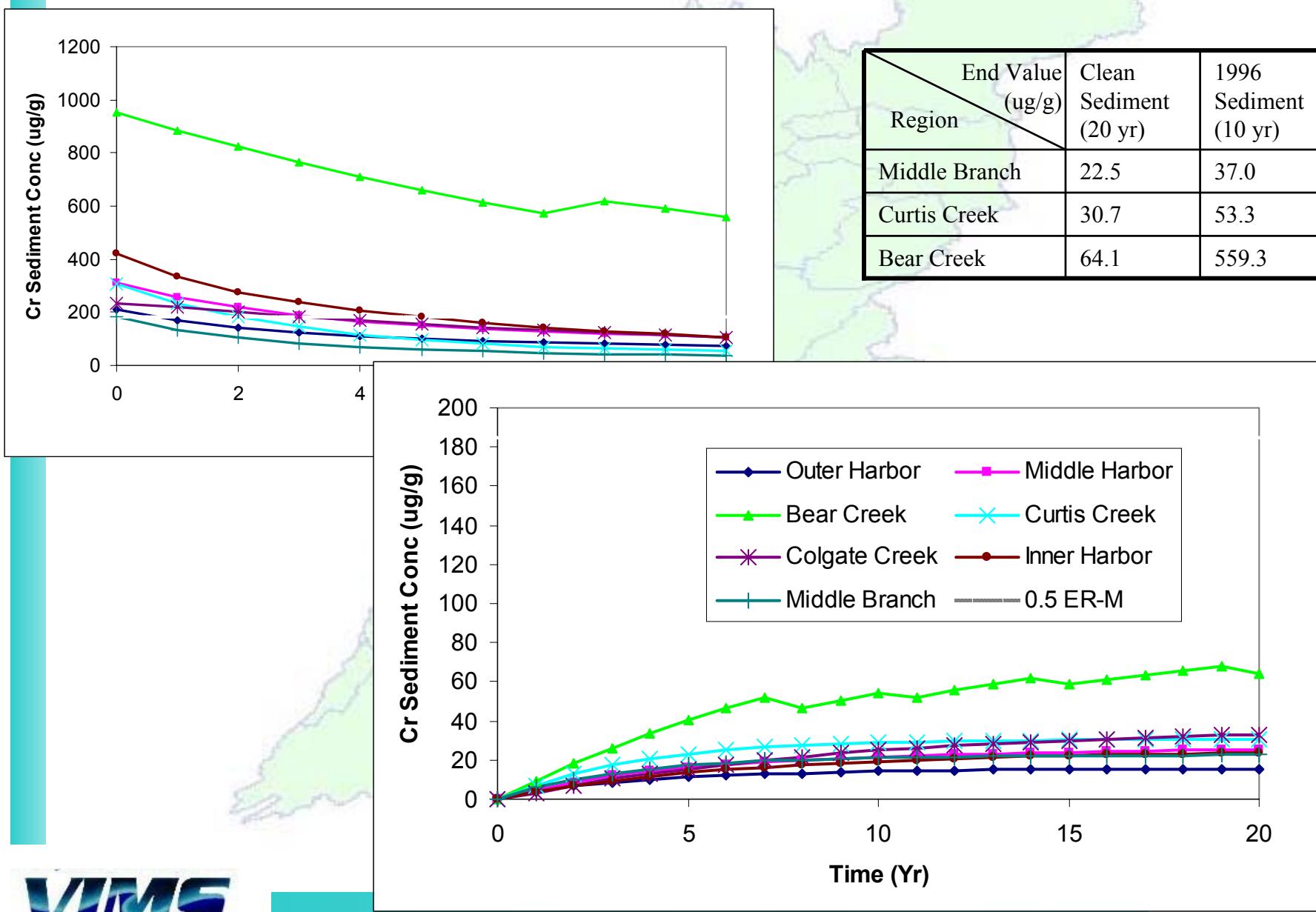
# Sensitivity Test-1: clean sediment (Pb)



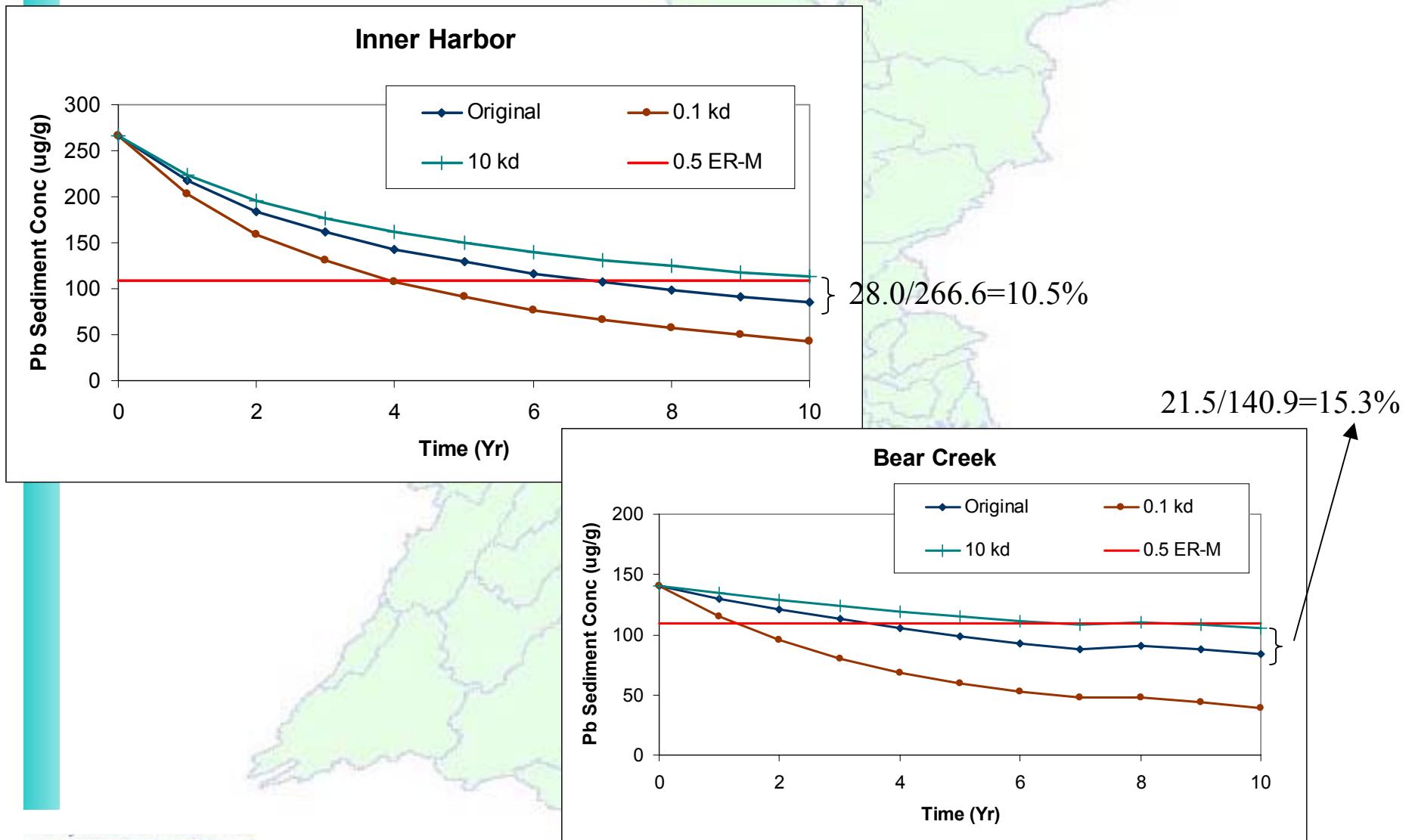
# Sensitivity Test-1: clean sediment (Zn)



# Sensitivity Test-1: clean sediment (Cr)



## Sensitivity Test-2: Partition Coefficient (Pb)



# Summary

- ICM/TOXI was set up to run long-term simulations
- The nonpoint source loading from the SWMM model results was incorporated into the model on a daily basis. The point source loading was read in monthly.
- Parameters used in the model are based on available field data and literature values to best represent real situations in Baltimore Harbor.
- With external loadings of year 2000, Pb, Zn and Cr sediment concentrations are generally decreased, indicating that a sediment legacy problem exists in the Harbor.
- Model results indicate that within 10 years, Pb MERMQ will drop to below 0.5 for all sub-areas in Baltimore Harbor; Cr MERMQ will be below 0.5 in areas except for Bear Creek. Zn MERMQ approach to, but still are above, 0.5 (especially Bear Creek) at the end of the 10-year simulation.

# Summary (CONT.)

- Among external sources, bay sources contribute more to the lower part of the Harbor, nonpoint sources are more important to the upper part of the Harbor, and point sources have more local effects.
- For Pb sediment concentration, nonpoint source is generally more important; For Cr sediment concentration, point source mainly has stronger impact; and for Zn sediment concentration, the relative importance of various external sources are different in different regions.
- The choice of partition coefficient could impact the rate of recovery based on model sensitivity test.